California Water

Bulletin No. 201-77

February 1978

CALIFORNIA WATER

By Way of Introduction . . .

With the publication of CALIFORNIA WATER, the Department of Water Resources launches a new kind of publication designed to draw a picture of what is happening in the State in water. We are doing this by presenting a group of articles in each annual issue that spotlight current water-related events, developments, and issues.

Every year DWR reports its activities and plans in a variety of technical publications that provide a great deal of information of particular interest to specialists in water management — engineers, hydrologists, water quality chemists, biologists, geologists, agricultural economists, and land use analysts, among others. However, CALIFORNIA WATER is intended to address a broad range of subjects in a nontechnical way.

When we first planned a general interest periodical on water use and management in California, our title sounded like a good choice. Now, as it happens, our first issue is coinciding with the most severe *lack* of water of California's 127-year history. Actually, this seeming contradiction is an advantage because two years of extremely dry weather and the resultant decline in water supplies have caught the attention of a large number of Californians who are now aware of the limited nature of our water resources. Today more of us are talking about water, reading about water, worrying about water (or lack of it), and working to save and recycle water.

So, for that reason, we are leading off this issue with a brief look at how California stands after our two record-breaking years of drought. Efforts to combat the drought's effects are, quite naturally, occupying a large part of DWR's attention. However, our year-in, year-out responsibility for watching over the State's water resources takes us into an enormous range of other activities as well. The articles presented here have been chosen to reflect the diversity of this subject. For instance:

- How DWR is managing the exceedingly difficult task of steering the State Water Project through California's worst drought
- DWR's strategy for California's "water future," particularly in ten problem areas of the State
- How — and why — DWR monitors and maps the growth of cities and farmlands in California
- Ways in which DWR is encouraging water conservation
- Steps being taken to improve the "drinkability" of water in some parts of California
- What DWR and other organizations can do (and are doing) to preserve the drought-troubled water-fowl habitat in the Suisun Marsh.

The task of giving direction to the overall development and management of California's water resources can be a lively one. When change occurs, as it often does, DWR must respond to it in new ways. In later issues of CALIFORNIA WATER, we plan to show how this sometimes happens, along with taking a fresh look at some problems that we are dealing with todav.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

California Water
Bulletin No. 201-77

Contents

A Look at Our Two Driest Years: California Water History in the Making 1
Less Now, More Later: DWR and Water Conservation 9
Drought Emergency Aid: The Davis-Grunsky Program Takes a New Direction 13
The Water Action Plan: A Blueprint for the Future 15
1978 May Be the Year for Action in the Delta 21
The State Water Project — 1976 and 1977: DWR Learns A Lot About Project Management in Dry Years 27
The Suisun Marsh: Its Future Depends on the Right Kind of Water 35
Repairing a Damaged River: The Trinity's Future Is Looking Better 39
Dry Year or Wet Year — Flood Management Planning Must Continue ....
Safe *and* Scenic: Levees and Flood Channels Must Meet Both Demands 51
The San Fernando Earthquake: A Close Call Brings Safer Dams to California 61
Surface Water + Ground Water = More Water for California 67
A Blanket of Water: Sierra Nevada Snow Is a Vital Source 75
New Funds for Old Water Systems 83
Vanishing Vegetation: The Face of the Sacramento River Is Changing — Rapidly 85
Keeping a Tally of California's Lands Aids DWR Planners 91

A Look at Our Two Driest Years

CALIFORNIA WATER HISTORY IN THE MAKING

As the realities of our present drought situation have been brought home to us, many Californians have found it difficult to believe that, in this day of great water development projects, California could be caught in such a predicament. For those of us who lived here at the time, memories of the State's last drought in the late 1920s and early 1930s have faded, and millions more of us are either new to California or are too young to have known those years. The drought is a new and often unreal experience for many, especially since its effects have not been equally felt. Some towns are living with mandatory water rationing, while others have so far escaped any special difficulty.

As the drought's influence has spread, the DWR Drought Information Center in Sacramento has received thousands of individual inquiries. The following discussion covers generally the type of information the Center was called on frequently to provide.

What is causing the drought?

The most obvious part of the answer is simply that less rain and snow have fallen on California than usual during the past two years. This is particularly true for Central and Northern California, which have received a little less than one-third the amount of rain this past winter (1976-77) they customarily get. For the whole State, precipitation was only slightly more than a third of normal.

Courtright Reservoir, Fresno County, on September 27, 1977. A Pacific Gas and Electric Company facility, the reservoir was holding only 2 percent of average storage on that date.

Less snow fell in mountain areas last winter than in any recorded year, eclipsing the winter of 1923-24, and nearly all of it had vanished by the first of April, the time of year it is usually deepest. This fact alone shows the enormity of the situation, because in California the water provided by melting snow represents a large portion of each year's total supply.

The real question is: what is causing less rain and snow to fall? The meteorologists tell us that the villain is a mass of high pressure extending hundreds of miles that has positioned itself off the coast of California each fall since the winter of 1975-76 and remained for months, blocking the path of most of our usual October-to-April storms. Most of these were carried around the State to the north, and moisture we would have normally received traveled instead to Canada and Alaska. Even the typically wet Pacific Northwest was much drier than usual. The few storms that did reach California were so weakened that they produced very little precipitation.

Why did this happen? Weather experts have speculated a great deal but have reach little agreement so far. A lot more study will be needed before the answer is found.

Isn't drought unusual for California?

No, although severe droughts are rare. The only other very dry period in this century occurred between 1928 and 1934. It was also the longest drought in the past 125 years. Not all those years were equally short of rain, however. Of the six winters, 1931 was the driest. The year 1924 was also notable. Until last winter, that was the driest year ever known.

We have records of droughts that occurred well back in the 1800s — 1827-29, 1856-57, and 1863-64. The last of these three followed closely the most tremendous flood ever known in California, when in 1861-62 deep water estimated to be about 32 kilometres wide (20 miles) and 400-480 kilometres long (250-300 miles) inundated the Delta and much of the Central Valley. This sequence of events demonstrates the wide range of possibilities in California weather.

Is there any way we could have anticipated this drought?

No, there really isn't. The study of weather records tells us, to some extent, what the weather *could* be, but at present we have no techniques that will disclose in advance when rain will fall. Our forecasting skill cannot even tell us what next week holds. Although researchers are working on the problem, as yet no method for making long-range forecasts has been proven reliable.

What is being done in this area?

For the past five years, the Department of Water Resources has taken the lead in supporting a program of research to find a reliable means of forecasting the weather as much as a year or even two years ahead. Several other State agencies and some federal agencies are also involved. DWR has a strong interest in the outcome of this work because dependable advance notice of weather changes is vital to effective water management planning.

Under this program, forecasts have been obtained from a meteorologist in the private sector, Dr. Irving Krick, and from Dr. Jerome Namias of Scripps Institution of Oceanography. The project is focusing in part on study of the relationship between sea-surface temperatures and seasonal weather.

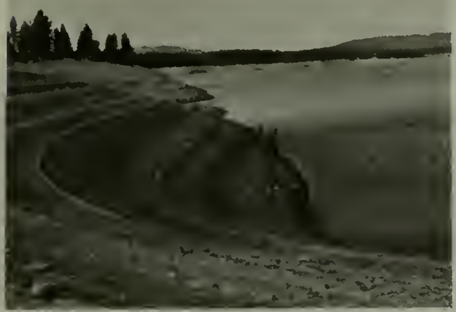
Results during the first three years were encouraging but inconclusive, partly because these were years of near-average rainfall in California. Dr. Krick's forecast for the 1976-77 water measurement year (October to September) called for an extremely dry year. This is intriguing, since the prediction was fulfilled. However, it is too soon to tell how much was due to validity of the method used. So far, the Scripps approach with sea-surface temperatures seems useful only in indicating trends in weather for the next six months.

How likely are we to have another drought like this?

What is noteworthy about our present state of affairs is the relative improbability, statistically speaking, of two winters as dry as 1975-76 (now third driest of record) and 1976-77 (driest of record) happening consecutively. The chance of that particular combination occurring is about 1 in 300.

Boat pier at Tahoe City stands where the level of Lake Tahoe is normally many feet deep. This was the scene in November 1977.

Boca Reservoir below Lake Tahoe in mid-November 1977, showing a greatly lowered lake level.



What problems are we having with our water supplies?

Taken as a whole, California does not have enough developed water supplies to meet its demands at this time. To visualize the problem, consider that a bucket filled with water represents the supply for the entire State — its reservoirs, ground water basins, streams, and all other sources. Now imagine that you ladle out half the water (our yearly water needs) and, a year later, put back only a fourth of what you took (our recent dry-year rain and snow). No matter what the size of the bucket may be, when you have done this for two years in a row, the level of the water in the bucket will have fallen very low. This is exactly what has been happening to California's water supply since the winter of 1975-76.

Each area of the State has a "bucket" of a different size, and, for two years, not a single area north of the Tehachapi Mountains has been able to return as much water as it has taken.

For a fuller understanding of the situation, one must consider the water dynamics of California. The State receives most of its water supply during a five- to seven-month period each year (October to April). In an average year, some 247 thousand cubic hectometres (200 million acre-feet*) falls as rain and snow. Of this amount, 87½ thousand cubic hectometres (71 million acre-feet) runs off into streams and reservoirs, where it is available for use. (Much of the rest sinks into the ground and replenishes underground reservoirs.)

In 1977, we needed 50½ thousand cubic hectometres (41 million acre-feet) to meet the State's total demand for water. We did not get it. We made up the difference by releasing water from reservoirs and by pumping from underground reserves. At present, California is having to deplete its surface reservoirs rapidly. From about 17 thousand cubic hectometres (14.1 million acre-feet) for an average year, the Central Valley's 36 major reservoirs today hold only about 5½ thousand cubic hectometres (4½ million acre-feet).

How is California benefited by release of this stored water during the drought?

Reservoirs are built and operated for a variety of purposes. They help protect downstream areas from potential floods, generate electric power, store water for irrigation, provide controlled flows for fish, and offer facilities for recreation. The larger reservoirs generally meet all these needs, while smaller ones may only serve certain of them.

The complexities of managing the State's water resources require that a good deal of the water stored in reservoirs be released each year. We cannot hold most of it on the chance next year may be dry, because California tends to have more normally wet years than dry ones.

In years of normal rainfall, a reservoir that is operated to control flood flows must be partly empty at the beginning of fall to ensure its capacity to hold winter rains and spring snowmelt from higher elevations. The storm water (called runoff) is released gradually during spring and summer in carefully regulated amounts to provide water for crop irrigation and other uses.

How come some areas are being restricted, when others have all the water they want?

Water supply systems in California function independently, with differing amounts of supply and differing rates of use. Most of these agencies have no ties with any other system. Therefore, one area's water supply and another's may have very little to do with one another.

The unequal occurrence of water in California (which arises from the fact that most precipitation falls in the north and most people live in the south) is a problem the State Water Project and the Central Valley Project were designed to help alleviate. Both projects do a great deal to distribute part of the abundant northern water to areas of need in the south, but they cannot handle every instance of unequal distribution. With greater development of interconnections among the thousands of individual water service agencies of all sizes in the State, many more Californians would be benefited, particularly in a time of water shortage.

Only occasional pools of water lie in the channel of the Cosumnes River in the fall of 1977.

*An acre-foot of water is the amount required to cover one acre to a depth of one foot. It equals about 326,000 gallons.

What are we doing about the drought?

The Department of Water Resources is deeply engaged in dealing with the drought emergency in a number of ways, and it will continue to do so, stepping up the pace of its involvement as needed.

In March 1977, Governor Brown established the Drought Emergency Task Force to bring together all drought efforts by the State under a single leadership. The Governor's order placed 18 State government organizations primarily affected by the drought in the group, including the Department of Water Resources, and named Major General Frank J. Schober, Jr., commander of the State Military Forces, to head the task force. The group is responsible for directing and coordinating State efforts to combat drought effects and for keeping the public informed of drought events and changes.

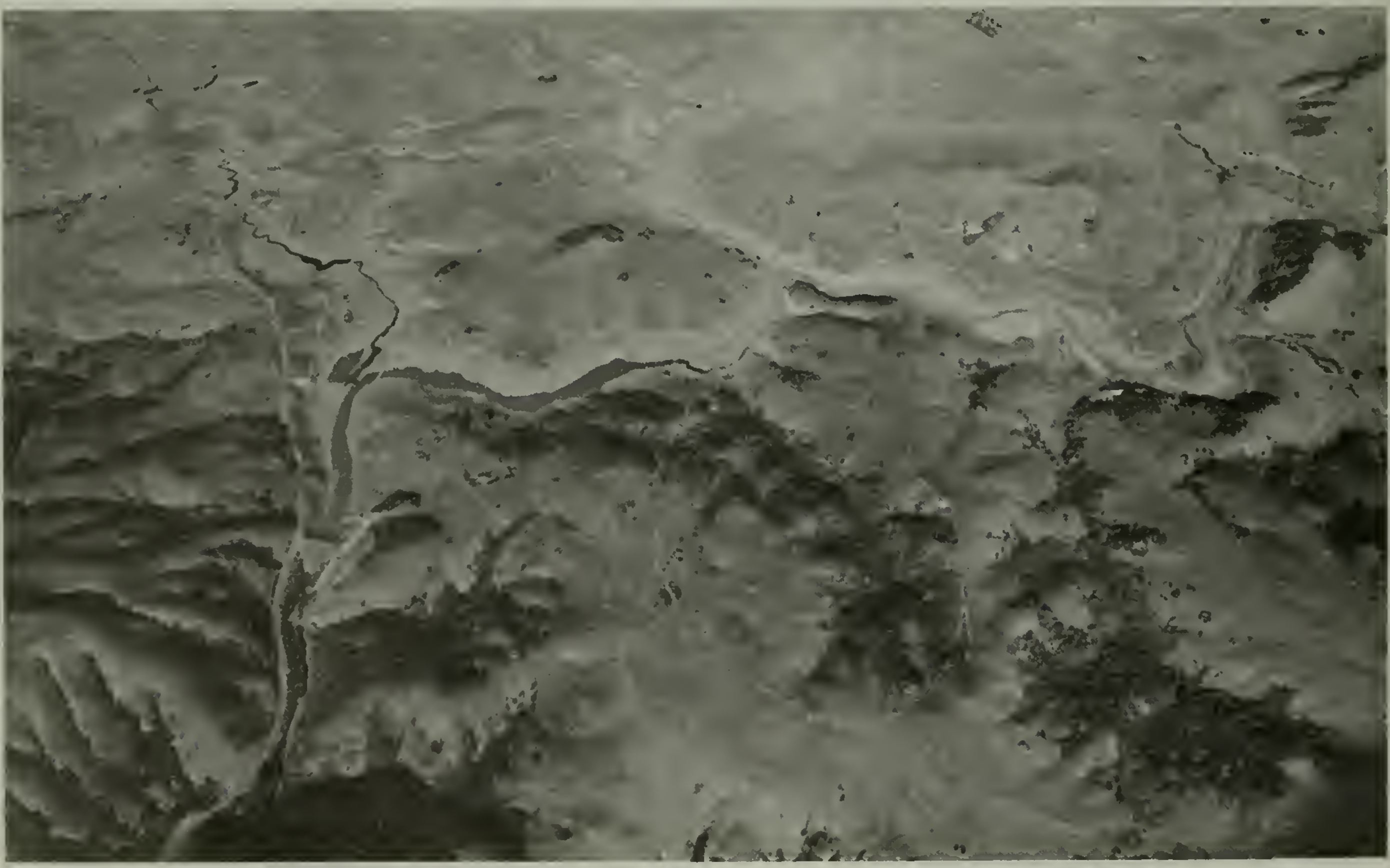
Another way in which DWR is responding to our water crisis is through the Drought Information Center, the State's clearing house in Sacramento for information on the drought. The Center's staff, which includes DWR personnel, draws on the resources of DWR and other State agencies and several federal agencies, all of which have drought-related responsibilities.

Since it was set up more than a year ago, the Center has fielded many hundreds of inquiries from the general public and others. Depending on the time of year, it has supplied such information as restrictions on use of State parks due to lack of water or the danger of fires in unusually dry forests; location and size of woodland fires; availability of boating, fishing, and other recreation at dwindling reservoirs and rivers; and sources of emergency loans or emergency water supply equipment for farmers and others whose water supplies are in difficulty.

In addition to numerous calls from individuals all over the State, newspapers and radio and television stations use the Center as a major source of current drought news; banks and other financial institutions often seek information related to the drought's economic impact; agricultural businesses and organizations call for farm-related drought information; and State and federal legislators contact the Center for answers to drought questions received from their constituents.

In the past several months, DWR has offered advice and State aid to local water service agencies in developing water conservation plans and putting them into action. DWR is working with the State Department of Education in preparing educational materials for the public schools to use in teaching water conservation and is also carrying out a statewide program aimed at encouraging Californians to reduce their use of water. Part of this activity is a large-scale test of the effectiveness of various home water-saving devices in six California communities. This is the most far-reaching program of its kind ever attempted. Throughout the State, communities have embarked on either voluntary or mandatory conservation, depending on the severity of their situation. More than 100 towns are rationing water, and almost every community in the State is restricting the use of water.

DWR has arranged water exchanges and diversions to move available water where it is needed most. In an agreement with DWR, the Metropolitan Water District of Southern California, largest water agency in the State, relinquished 493 cubic hectometres (400,000 acre-feet) of State Water Project water they had contracted for. This water was delivered instead to San Joaquin Valley farms and city dwellers in the San Francisco Bay area. MWD is replacing this water with water from the Colorado River. In another example of interagency cooperation, SWP water from the Delta is being routed through three successive Bay area water agencies across San Francisco Bay



Nicasio Reservoir, Marin County, on October 10, 1977. Owned by the Marin Municipal Water District, it held 2 percent of average storage. Heavy rains in the region in the fall of 1977 brought the reservoir up to 12 percent by December 1.

in a specially built pipeline on the Richmond-San Rafael Bridge to Marin County, where it is urgently needed. Delivery of this water began in June 1977.

Temporary rock barriers built by DWR at key points in the Delta are redirecting flows to prevent the intrusion of salty ocean water into its waterways.

A cloud-seeding program financed by DWR was carried out in Northern California for a time last summer. More cloud seeding may be carried out this winter. DWR has also agreed to permit San Joaquin Valley farmers to store excess pumped ground water in the SWP's California Aqueduct for later withdrawal when they need it.

Actions by other State agencies to combat the effects of the drought include these:

The Department of Fish and Game (DFG), DWR, and several private duck clubs have combined to pay for the delivery of fresher water to wildlife areas of the Suisun Marsh impaired by the intrusion of salty water. The drought is upsetting the important salt/fresh water balance of the marsh.

The Office of Emergency Services, the California Conservation Corps, the California National Guard, and the Department of Transportation have been loaning materials and equipment to public water agencies in areas critically short of water. These agencies have supplied tank trucks to haul water, pumps, generators, water pipes, water purification units, and tanks for storing water. Nearly every Northern California county and some coast counties have been aided in this way because they have been hardest hit by the drought.

To make the most of water still available, the State Water Resources Control Board has issued modified standards for controlling the quality (salinity) of water in the Delta and has directed several large water agencies, one of them DWR, to hold water in reserve in upstream reservoirs in the event 1978 is also dry.

The Public Utility Commission ordered utilities in several critical areas to ration water and directed certain agencies to distribute water-saving home devices and prepare rationing plans.

DFG is working to save fish and wildlife endangered by the drought by carring feed to wildlife areas, moving trapped fish from drying streams to sites having sufficient water, and drilling wells in waterfowl habitats to supply water needed by plants the birds feed on.

In recreation areas administered by the Department of Parks and Recreation, landscape watering has been sharply cut back, water-saving devices have been installed in restrooms, and some facilities have been replaced with chemical toilets.

The Department of Transportation (Caltrans) has also cut back landscape watering along freeways, as well as changed to nighttime watering, pruned plants to reduce the need for water, removed plants entirely at some sites, halted all replanting, and begun the use of reclaimed water. If the drought worsens, Caltrans will stop watering altogether.

Greatly lowered levels at several reservoirs have allowed the Department of Navigation and Ocean Development to lengthen boat-launching ramps.

The State Legislature has enacted a number of drought-related bills. It has provided tax relief for livestock ranchers, on whom the effects of the drought have fallen so drastically; authorized DWR's test program of water conservation kits for the home; broadened loan programs for farmers and small water service agencies; and authorized water agencies to put water conservation programs into action.

Why is it difficult to anticipate a drought?

The greatest difficulty in meeting drought demands is knowing when they will occur. As explained earlier, we know some years

Lake Oroville, Butte County, on September 30, 1977, when storage was 36 percent of average. This is an aerial view of the upstream side of Oroville Dam. The reservoir and dam are facilities of the State Water Project operated by the Department of Water Resources.

will be wet (or wetter) and some years will be dry (or very dry), but that's about it. When proven techniques have been developed, we will be able to foresee droughts and prepare ourselves for them.

The State Water Project is a major supplier of water to water agencies, indirectly serving a major part of the population of California. When the project was in its inception during the 1950s and 1960s, planning was based on all conceivable types of water years, from the driest to the wettest known at that time. Unfortunately, our last major drought in the 1920s and 1930s, which was the best information available, led SWP planners to believe that was about the driest weather we were likely to encounter.

Another source of difficulty is the change that has taken place in California since those days. Our population in 1930 was a little more than 5½ million. We now have more than 21 million people. In 1930, about 1.7 million hectares of farmland (4.2 million acres) were under irrigation. Today we irrigate more than 3.6 million hectares (9 million acres). These changes mean more demands on our water supplies in all types of years.

However, our position is not as unfavorable as it might have been because, by the end of 1975, DWR was already predicting that a serious dry period might be developing. Its "Special Report on Dry Year Impacts in California," published in February 1976, warned of what could lie ahead and outlined many measures that could be used to moderate the effects of a serious statewide shortage of water. That winter DWR also began to modify somewhat the operation of the State Water Project in preparation for what it saw as a good chance the year could continue to be unusually dry. Events have shown that was a wise move. In future operations of the project, DWR will be armed with an invaluable store of information gained during this drought and will be prepared to meet the challenges of another dry period.

Lake Shasta, Shasta County, on September 30, 1977. The reservoir was storing 20 percent of average on that date. This is a Central Valley Project facility operated by the U. S. Bureau of Reclamation.

When will we know the drought is over?

With the opening of the 12-month water measurement period that began last October, California entered its third potentially dry year with several strikes against it. Soils in foothill and mountain watersheds were critically short of moisture, some ground water basins had been overdrawn, and reservoirs held record low amounts of water. All these conditions must be fully overcome before the State's water situation can be considered back to normal.

Although many years will have to pass before all the harm brought by the drought has been erased, California should once more be in good shape when we are able to store more water than we use. This will not mean we can return to our former wasteful ways of using water. If the drought has taught us anything, it is that we must live in moderation, bearing in mind that dry cycles are normal for California and they will return from time to time.

More on the Drought . . .

Four reports published by DWR in the past two years provide comprehensive coverage of events and results as they have developed during this period. Copies are free of charge.

Special Report on Dry Year Impacts in California. February 1, 1976.

The California Drought - 1976. May 1976.

The California Drought - 1977; An Update. February 15, 1977.

The Continuing California Drought. August 1977.

A procession of storms sweeping out of the Pacific across California during December 1977 brought rain to the entire State and snow at higher mountain elevations. As a result, by the end of the month, measurement stations at many larger cities were reporting seasonal rainfall at near-normal or slightly above-normal levels. The storms continued in January, almost without letup. California was drenched by unusually heavy amounts of rain that brought the totals to well above normal levels. Mountain snowpacks built quickly to depths that had not been seen for several seasons. Reservoir levels began rising, and streams were once again running, some near flood stage for a time. If the winter of 1977 - 78 continues to be a wet one, prospects are bright for a good supply of surface water as we go into spring and summer.

What can we do to be ready for another drought?

Probably the best way to cope with another drought is to plan for it. All cities and major water agencies and State, federal, and other government agencies with water-related responsibilities should have drought contingency plans so that, as future dry periods begin to take shape, they can start taking action to offset their effects.

The present drought is teaching us a lot about what can happen and what steps to take to counter it. When this drought has ended, water managers throughout the State will have many strategies they can call on to ensure our future well-being. One solution, mentioned earlier, is to improve the physical interconnections of water supply systems.

Another way to combat future droughts is to place water in our vast underground storage reservoirs in years when rain and snow are plentiful, to be drawn out again in years of shortage. These ground water basins supply about 40 percent of California's need for water. Other ways to protect ourselves is to make strong efforts to save water and use recycled water.

LESS NOW, MORE LATER

DWR and WATER CONSERVATION

Imagine, if you will, a large, new dam somewhere in California. The lake behind it is long and deep, and an adjacent hydroelectric plant generates an enormous amount of energy each year. What's more, neither the dam nor the power plant poses any threat to the environment. They mar no valley, block no river. No scenic vistas are sacrificed for the sake of water or energy.

Although the dam is imaginary, its potential benefits are quite real, for in a state the size of California, where each of the 22 million residents uses nearly 800 litres of water a day (about 200 gallons), the introduction of simple conservation devices into homes and apartments can reap billions of litres in annual water savings, savings that represent 6.6 million barrels of oil worth $100 million. If residents take similar precautions *outside* their homes, especially in their gardens, these savings can be more than doubled.

The Department of Water Resources believes in the great potential of water conservation in the home and elsewhere, and gives the concept high priority in its water management program. Water conservation must be a long-range effort. We need to make it a part of our everyday lives in both wet and dry years. The continuance of the drought underlines the importance of all conservation measures. Although saving water has always been sensible, today it is a necessity.

The home is not the only place for water savings, of course. Farms, businesses, industry, schools, and hospitals and other institutions can all contribute in varying degrees to the overall saving of water. However, the programs discussed here focus on what individual Californians can do and are doing.

More than a year ago, in a report titled "Water Conservation in California," DWR laid down a series of water-saving ideas and began a program of public service TV and radio announcements to spread the word to the general public; this campaign continued through 1977 with the "Save Every Last Drop" theme. The most ambitious part of the save-water drive began in early 1977 with six pilot water conservation studies conducted in various communities around the State. The largest of these was carried out in Southern California, in the City of San Diego, where DWR distributed nearly 180,000 water-saving kits free of charge in residential neighborhoods.

Designed especially for the bathroom, these kits consisted of flow restrictors for showers, devices to reduce water use by toilets, and dye tablets to check for toilet leakage. In addition, low-flow shower heads, other toilet devices, and external shower restrictors were made available by mail. The home bathroom was the target of this phase of the campaign because it accounts for 75 percent of the water used inside the typical home. DWR is now evaluating the effect of these kits.

In dollars and cents, the annual utility savings amount to $5.90 for each household with a gas water heater, and $18 for each household where the water heater is electric. In San Diego alone, the energy savings would total a whopping $3 million a year. And at $40 per acre-foot, the unused water has an annual value of $525,000.

DWR distributed the water-saving kits in three ways. First, 276,000 residents were sent postcards encouraging them to pick up kits at neighborhood depots. Then, another 60,000 residents received their kits by door-to-door delivery. Finally volunteers and members of the California Conservation Corps called at 20,000 households to talk to homeowners and hand them the kits. This three-phase distribution program coincided with an intensive public information drive and is being followed by a marketing survey to show which phase was most successful, and why.

San Diego was chosen as a test site because, unlike some other California cities, it has no critical water shortage. And since the city is relatively isolated — compared, say, to Los Angeles — it is well-suited to an intensive distribution effort.

Besides San Diego, water-saving kits were also distributed in the cities of Santa Cruz, El Segundo, Oak Park, and Sanger, and in the El Dorado Irrigation District in Placer County. Although none of these other programs was as large as the one in San Diego, they involved thousands of households around the State. If these new water-saving programs prove successful, expansion may continue into other communities, especially if financing can be arranged through a matching-fund agreement between DWR and local agencies.

Conservation Kit Distribution

Community	Type of Community	Number of Households	Water Critical?	Mandatory Rationing?	Cost of Kit	Number of Kits
San Diego	Urban	374,000	No	No	Free	180,000
Santa Cruz	Urban	57,000	Yes	30% Reduction	Free	26,000
El Segundo	Urban	6,000	No	10% Reduction	At Cost	272
Oak Park (Los Angeles County)	Urban	753	No	No	Free	667
Sanger	Rural	3,000	No	No	Free	1,200
El Dorado Irrigation District	Rural	12,000	Yes	67% Reduction	At Cost	4,600

Water-Saving Gardening

The old saw about seeing is believing is the concept behind a new type of garden flourishing in downtown Sacramento at 17th and N Streets. The project is a living demonstration that outdoor residential greenery can survive and thrive, despite a shortage of water. The garden shows home gardeners how to select and plant a less-thirsty landscape. The choices are wide — shrubs and flowers, plantings that act as barriers or provide privacy, turf for children's play areas, ground covers, and shade plants — all species that do well with very little water.

The garden has been designed along two lines. One is the immediate situation: making more efficient use of water for gardens already planted, such as drip systems and soaker hoses for irrigation, and adopting moisture-conserving practices, such as mulching and composting. The other approach involves the long-range view: designing a landscape based on plants that need little water and are best suited to the climate in an area.

Developed jointly by the Department of Water Resources and the State Office of Appropriate Technology, the drought-tolerant garden has attracted the interest of hundreds of visitors since it opened in May 1977. Community participation has also been an important part in its development. Many neighborhood residents have volunteered to help build a patio, a gazebo, and a tool shed, and do some of the planting. The idea of water-saving gardening has caught on elsewhere in the State, too. Demonstration gardens are being planted in at least 18 other locations.

Staff and visitors at DWR's Drought Tolerant Garden in Sacramento take a look at the progress of several types of flowers that need little watering.

Captain Hydro to the Rescue!

With his cape flying, a colorful cartoon character known as Captain Hydro is appearing in special teaching materials that are introducing tens of thousands of California school children in the fourth, fifth, and sixth grades to the idea of water conservation. Based on the highly successful educational materials developed by the East Bay Municipal Utility District in Oakland, the Captain Hydro program emphasizes the need for long-range water awareness and saving.

Developed jointly by DWR and the State Department of Education, the program relies on local cooperation between the schools and water supply agencies. Basic financing comes from an Environmental Protection Program grant. Materials are sold at cost in large quantities to participating schools and water agencies and supplemented by teachers' booklets written for seven regions of the State. The program costs about 25 cents per student at the local level.

Judging by early orders, at least one-third of the million children in the three grade levels during the 1977 - 78 school year can be expected to learn how vital the saving of water is to California.

Impact of the Drought: Marin County

DWR landscape architect explains layout and plans for Drought Tolerant Garden to visitors, while volunteers help with planting and building

What does a severe drought and water rationing do to the inner workings of a community?

How much water can people live with and yet live as well as they did when supplies were far more ample?

When a drought ends and water is again plentiful, are people likely to start using as much water as they did before the drought?

DWR is looking for the answers to these and other questions through an in-depth examination of attitudes, impacts, and economic consequences of the acute water shortage in Marin County. Marin has been among the most severely hit areas in the State and one where the drought was felt earliest. Therefore, DWR is keenly interested in discovering how the county is coping with the situation and whether its experience is providing answers that can be applied elsewhere in the State.

In February 1977, DWR began mailing questionnaires to about 10,300 individuals, families, and organizations in the more heavily populated eastern part of the Marin Municipal Water District's service area and in Marin County and southern Sonoma County generally. With the cooperation of local water agencies, DWR contacted residents of single-family dwellings and apartments, operators of stores, restaurants, nurseries, and livestock and dairy farms, city administrators, and officials of State and local agency offices in the area. Acknowledgment was high. Slightly more than 50 percent of those queried completed and returned their questionnaires, indicating a high degree of interest in the survey. The results of this comprehensive study have been compiled and analyzed and will be published by DWR in the near future.

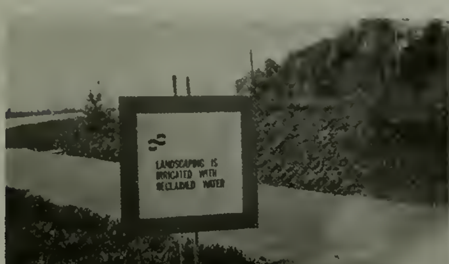
Employees of the Paradise Irrigation District in Butte County spend much of their time showing residents of the area how to read their water meters. They recommend reading them daily to detect leaks early and to be certain their estimates of use are correct. The town of Paradise is one of many foothill communities seriously troubled by a lack of water.

In the meantime, DWR has selected at random 1,000 of the more than 4,500 responses from single-family households served by MMWD. The purpose was to take a preliminary look at residential reaction to drought conditions. These were people whose use of water has been sharply cut for two years. Twenty-five percent rationing was imposed by the district in 1976 and, in early 1977, when the situation had deteriorated even more, a 57-percent cutback was ordered. Response was excellent, particularly in 1977, when consumption dropped to almost 63 percent. The penalties imposed for exceeding the daily allotment of 46 gallons per person and the rise in the price of water have done much to encourage water conservation. Rates for water have tripled since the drought began.

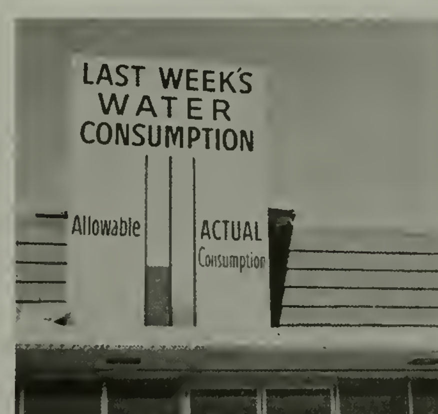
Some of the results of DWR's preliminary study show that setting a limit on the amount of water that can be used is a successful means of reducing the consumption of water. Under normal conditions of water supply, the more affluent families tend to use a significantly greater quantity of water, but with stringent rationing, families of all income levels are able to bring their consumption down to nearly the same low rate. The drought experience in Marin County is demonstrating that people can and will manage with less water than was once thought adequate. The drought is also responsible for another change. Ninety-four percent of the households responding state they would now accept reclaimed water to maintain outdoor landscaping.

Information for this article was contributed by P. Kay Griffin, Associate Engineer; Donald C. Heath, Staff Services Analyst; and Lisa McAndrews, Graduate Student Assistant; all of the Water Conservation and Supply Branch, Sacramento.

Approaches to the current significance of water conservation are discussed more fully in "Water Conservation in California" (Bulletin No. 198), published by DWR in May 1976. This 106-page report is available free of charge.



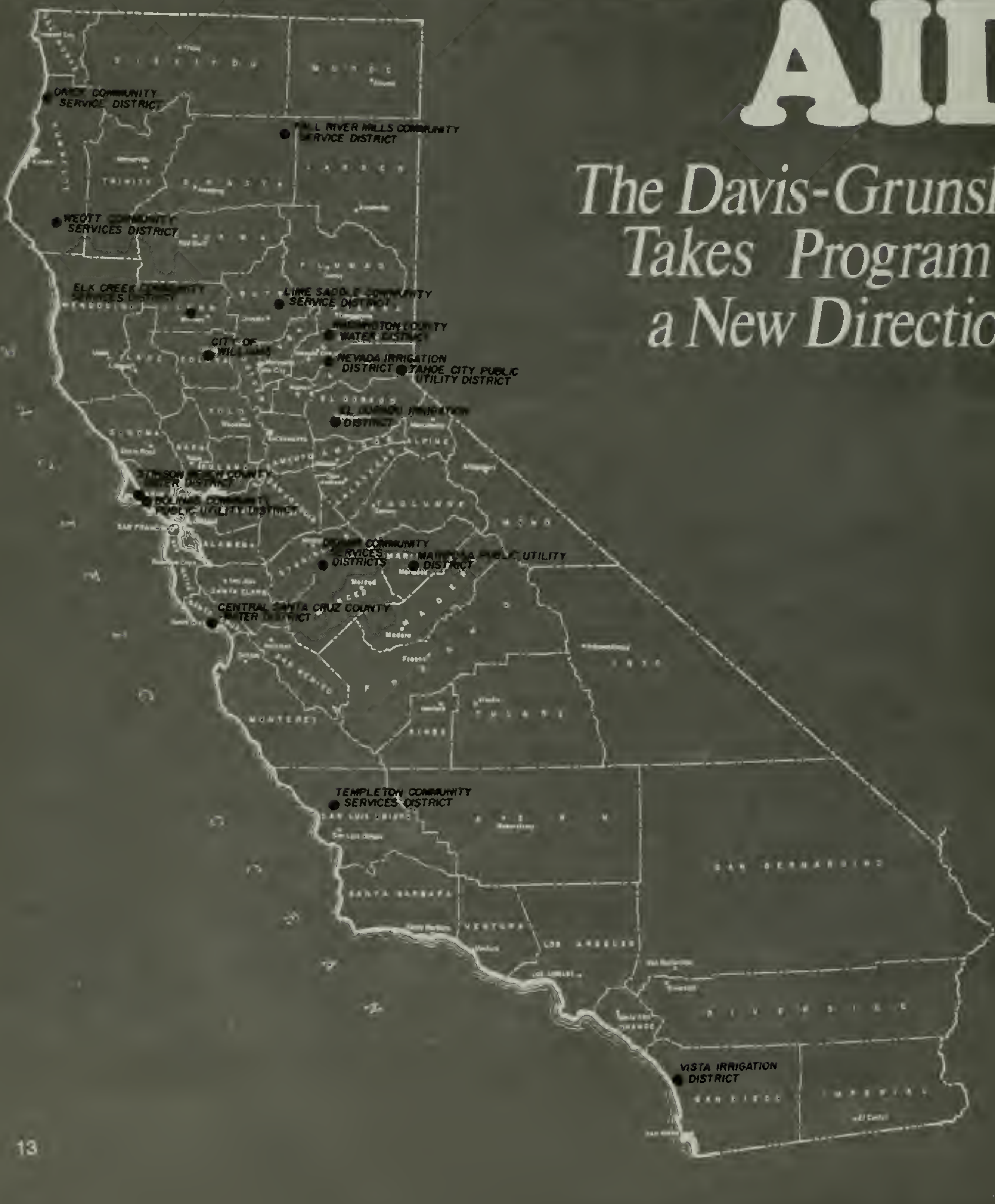
Grounds at the Marin ferry terminal in Greenbrae.



A sign over the office of Marin Municipal Water District in Corte Madera keeps customers informed of their success in reducing water use.

DROUGHT EMERGENCY AID

The Davis-Grunsky Takes Program a New Direction



The Davis-Grunsky program of State aid to local agencies for water-related recreation and water supply development is nearing the end of a long period of public service at the grassroots level.

Nearly $109 million has been either loaned or granted outright to local agencies in 34 California counties since the program began in 1959.

More than 103,000 Californians get water from systems aided through the loan portion of the program, and in 1977 nearly four million persons enjoyed recreation at water project facilities built under the grant part of the program.

The end of the program is impossible to predict, since it depends on the rate at which local agencies apply for money in the various (and recently expanded) loan and grant categories. As of the end of 1977, about 79 percent of the original $130 million appropriation had been spent or committed and applications for about $13 million of the remainder were in hand.

A new element of the program enacted in 1976 — emergency aid to small communities stricken by the drought — may step up the pace of the Davis-Grunsky program. The first low-interest loan to be approved under emergency provisions granted $35,000 to the Lime Saddle Community Services District in Butte County in February 1977 to drill a well to supplement dwindling water supplies for a community of 150 persons.

Drought emergency loans to build critically-needed water supply facilities can be made to public agencies serving 200,000 persons or less.

The Davis-Grunsky Act was enacted by the Legislature in 1957 as the Grunsky Act in a much more modest form than the present act. Eligibility for loans was limited to public agencies for flood control; for diverting, storing, and distributing water, chiefly for domestic, municipal, agricultural, or industrial use; and for generating electric power.

Grants were available for water development projects that included preservation of fish and wildlife and promotion of recreational facilities as incidental parts of their plans. Projects primarily intended for these purposes were not eligible. Both loans and grants were available only upon specific authorization of the Legislature.

In 1959, a bill introduced in the California Senate greatly expanded the program by providing financing through a $15 million revolving fund and by providing for grants up to $300,000 and loans up to $4,000,000, subject only to the approval of the California Water Commission. Larger sums required specific authorization by the Legislature. This bill made the Department of Water Resources responsible for determining an agency had no other source of money for the purpose and for extent of public need, the engineering feasibility, the urgency, and the economic justification.

Senate Bill 425 provided that if the California Water Resources Development Bond Act (the Burns-Porter Act, which made possible the construction of the State Water Project) was enacted into law and the $1.75 billion bond issue was approved by the voters in November 1960, the $15,000,000 revolving fund would be abolished and the program would be funded by part of the new bond act. The voters did approve it, and the Davis-Grunsky program became a reality.

The program is administered by the Department of Water Resources under the general control of the California Water Commission. Regulations and policy that guide it have been jointly adopted by the Department and the Commission. The Commission retains final control of most expenditures. Today, approval of the State Legislature is needed for grants of more than $400,000 per project, construction loans exceeding $4 million per project, and feasibility report loans of more than $50,000 per project. An exception is the drought emergency loan, which the Department can provide without approval of either the Commission or the Legislature.

Expenditures in the early years of the program were largely for administrative costs, but by 1963 annual payments had nearly reached the $3 million mark. The largest spending year so far has been 1968, when a total of $15,565,627 was paid out. By 1973, the impact of a policy shift that placed emphasis on water supply loans was being felt, and as the number of large grants declined, annual expenditures fell to the $3- to $5-million level. Expenditures in 1976 rose to nearly $7 million with a $3.5 million loan to the Paradise Irrigation District.

Nine types of aid are now offered to local public agencies under the Davis-Grunsky program:

- Grants for the recreation portion of the cost of building any dam and reservoir.
- Grants for the part of the construction cost of a project allocated to fish and wildlife preservation.
- Grants for building initial water supply and sanitary facilities for public recreation at each dam and reservior.
- Construction loans for local water projects.
- Feasibility report loans.
- Drought emergency loans.
- Reservoir site loans.
- State participation in local projects.
- Dam and reservoir rehabilitation loans and grants.

Recreation and Fish and Wildlife Grants

Grants may be made for the part of a project's dam and reservoir costs designated for recreation or for protecting fish and wildlife. Funds may be granted only to projects that will develop new water supplies and are limited to half the cost of building facilities for either recreation or fish and wildlife. In total, these grants cannot exceed 75 percent of the total construction cost. Grants may also be made to build initial water supplies and sanitary facilities for public use at each dam and reservoir. They are limited to a fourth of the total granted toward recreation and fish and wildlife.

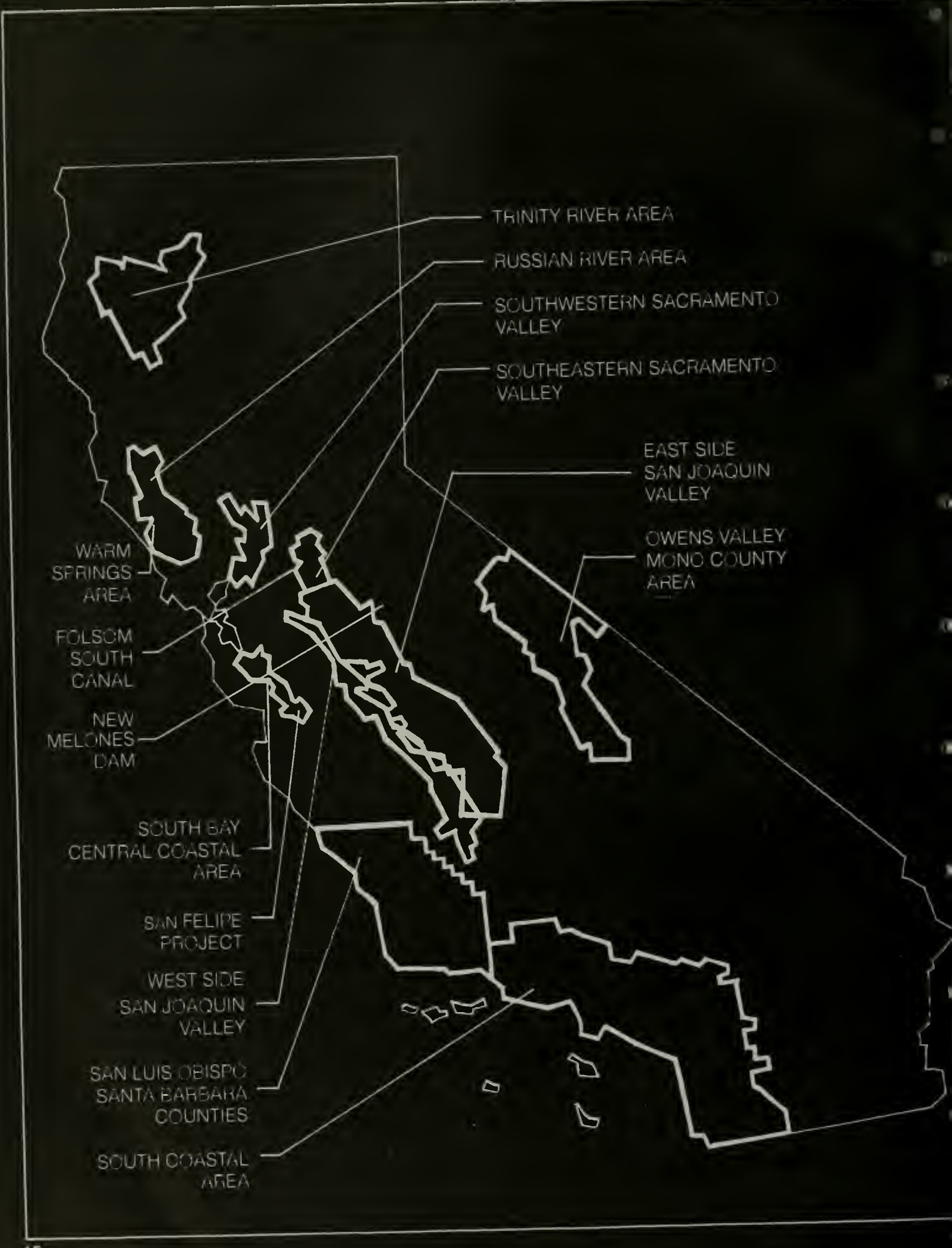
By the end of 1977, 33 grants totalling $62,189,653 had been approved for 28 local agencies.

Loans for Water Projects

This program provides money to local agencies to purchase lands (or interest in lands) to construct, operate, or maintain projects that would meet their water supply needs. The agency must be unable to finance the work from other sources and must repay the loans in full plus interest at a rate of 2½ percent. As of the end of 1977, this element of the program had not been used.

The State can also become a partner with local agencies to build local projects larger than originally proposed. An example of this is a relatively small dam planned for a site that is actually suited for a larger structure that will serve more people for less cost. With approval of the California Water Commission, DWR may spend up to $1 million to take part in any one such undertaking. Larger amounts require legislative approval. This portion of the Davis-Grunsky program has not been used.

Information for this article was contributed by Donald Engdahl, Associate Governmental Program Analyst, Water Conservation and Supply Branch, Sacramento.


TRINITY RIVER AREA
RUSSIAN RIVER AREA
SOUTHWESTERN SACRAMENTO VALLEY
SOUTHEASTERN SACRAMENTO VALLEY
EAST SIDE SAN JOAQUIN VALLEY
OWENS VALLEY MONO COUNTY AREA
WARM SPRINGS AREA
FOLSOM SOUTH CANAL
NEW MELONES DAM
SOUTH BAY CENTRAL COASTAL AREA
SAN FELIPE PROJECT
WEST SIDE SAN JOAQUIN VALLEY
SAN LUIS OBISPO SANTA BARBARA COUNTIES
SOUTH COASTAL AREA

THE WATER ACTION PLAN

A BLUEPRINT FOR WATER MANAGEMENT

The California of 1977 is a vastly different place from the California of 20 years ago, when the California Water Plan was published by the Department of Water Resources. In 1957, with a population of close to 14 million, the State's progress was measured almost entirely in terms of economic growth. The relationship of such growth to the environment and the potential impact on our attractive and bountiful natural resources was not well defined. Events in the past two decades have gradually worked a change in our thinking, however, until today there is a greater concern that our limited natural resources must be conserved and protected for future generations to enjoy. Nothing could be bringing home the importance of this concept to the field of water resources quite as forcefully as the present drought and the need to allocate the perilously small amount of water available to us.

Water is universally recognized as a basic necessity for homes, agriculture, and industry. However, since 1957, we have come to see water in other ways, too — as a habitat for fish and other aquatic life, as a setting for recreation, and as a resource with an esthetic value of its own. As a result, we are learning that the historical and traditional means of water management which is based largely on building dams, canals, and other physical structures, must be accompanied by other methods aimed at stretching our present supplies and making the best use of them in a carefully balanced manner.

As a comprehensive master plan set forth to meet the State's water requirements over an indefinite period, the California Water Plan outlined a broad pattern for the orderly development of the water resources of all California and continues to be the cornerstone of the State's water resources activities. The idea behind it was "to provide a logical engineering basis for future administration of the water resources," so that the needs of all areas and all people would be equitably satisfied.

Recognizing the reality of changes that have occurred since the statewide plan was formulated, the Department of Water Resources (DWR) is now taking a fresh look at significant water issues facing California and suggesting specific ways of resolving them, in line with today's social and environmental goals. This new approach is called the Water Action Plan. (Status of the plan will be reported in the update of the California Water Plan scheduled for publication in Bulletin No. 4 at the end of 1978.)

The Water Action Plan cannot solve all California's water problems for the next 100 years because conditions change too rapidly. What it does do, however, is concentrate on developing specific courses of action to solve specific problems, immediately and in the near future, during the 22 years remaining in this century.

The Water Action Plan covers four basic subjects: water conservation, study of major water problems in 10 geographic areas of the State, coordination of federal and State water project operations, and review of facilities needed in the Delta to meet the requirements of State and federal water projects.

This planning effort will touch the lives of all Californians in many ways. Among other things, it will:

- Act as the basis for a State water conservation policy
- Identify specific local projects (reclamation of waste water and conjunctive use of surface and ground water) to receive financial and technical aid from the State
- Establish the State's position on water quality control and land use policies
- Determine what actions are needed to ensure that the State Water Project meets its various commitments
- Give greater consideration to the needs of fisheries, wildlife, and recreation

Water Conservation

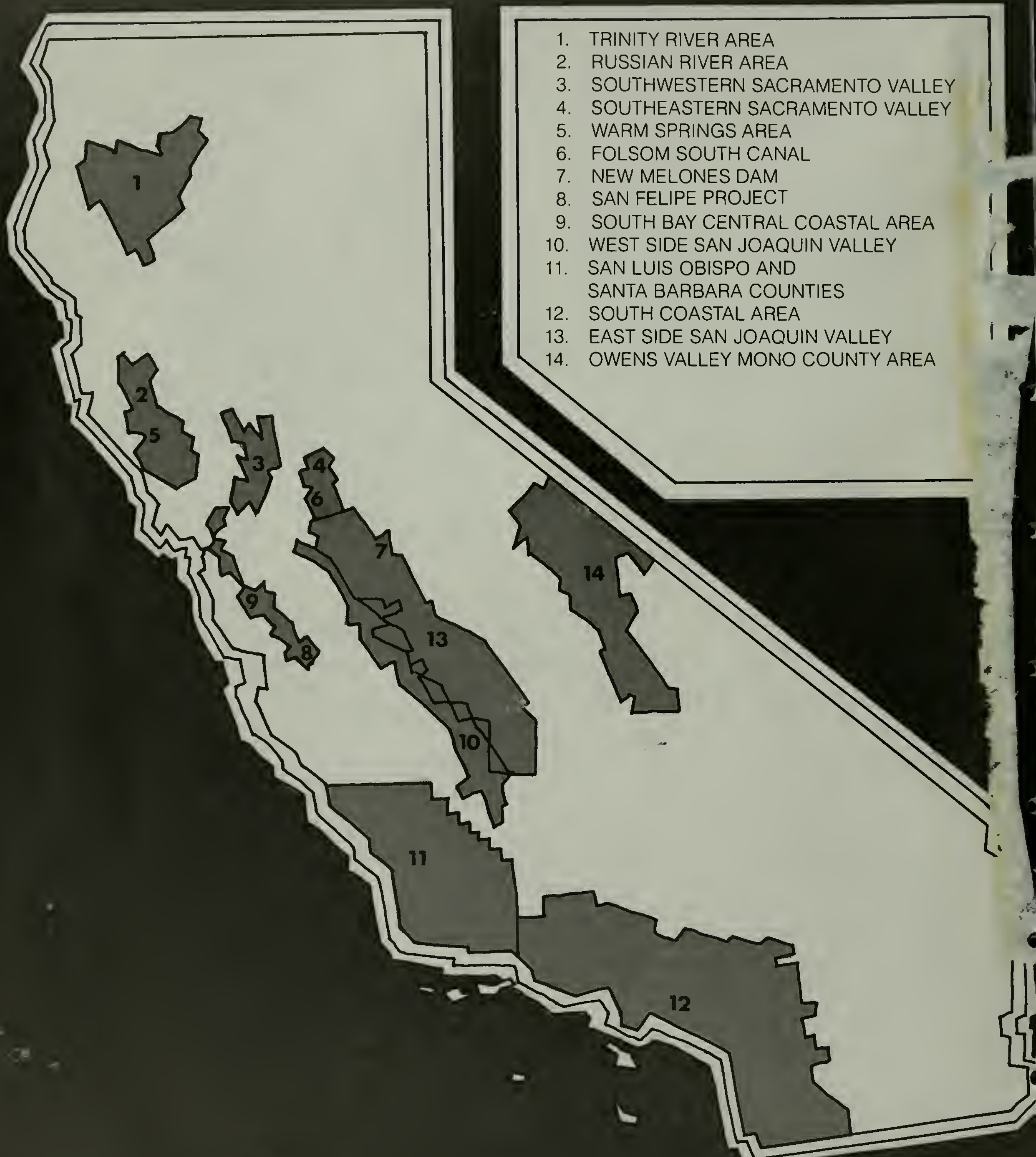
A good starting point for any water management planning is an estimate of future water demand. Bearing directly upon the size of that demand is the exercise of effective water savings practices. Thus, the first study element of the Water Action Plan is water conservation. (Departmental efforts to promote water-saving practices are discussed in the article, "DWR and Water Conservation," elsewhere in this issue.)

Water conservation, when practiced continuously, prevents the waste of water, saves the electric energy used to pump, heat, and treat water, and extends the use of presently developed supplies, thus postponing the need to develop additional supplies.

Problem Areas

Ten regions of the State have been identified as having critical water problems or as representing issues that require immediate solution. These are matters that could be solved through action by State government. In several study areas, the State needs to either develop or modify its position on the allocation of water from certain federal water projects. These include the Warm Springs Project, the Folsom South Canal, the New Melones Project, the proposed Mid-Valley Canal, and the San Felipe Project.

AREAS STUDIED UNDER THE WATER ACTION PLAN



Defining and correcting problems connected with the fish habitat and streamflows in the Trinity River is a key issue in the Trinity River area. Solutions considered include watershed restoration work, increased flow releases below Lewiston Dam, hatchery modifications to control water temperature and fish disease, and construction of a debris dam on Grass Valley Creek. (See the article, "The Trinity Is Looking Better," elsewhere in this issue.) Another important problem in the area is maintaining the fullest possible yield of the Trinity River Division (part of the Central Valley Project).

Finding ways of meeting the future demand for water in the Folsom South Canal service area is a major issue in eastern Sacramento and San Joaquin Counties. In these parts of southeastern Sacramento Valley, declining population growth and the high cost of converting marginal farmlands to productive acreages through irrigation are bringing about a reexamination of the area's future need for water. Instream uses of the lower American River — such as rafting, fishing, swimming, and other leisure activities, and habitat for fish and wildlife — are another major concern in this area. The solution hinges on arriving at an equitable distribution of available river flow.

In southwestern Sacramento Valley, earlier investigations have shown a need for more agricultural water for parts of Colusa, Yolo, and Solano Counties and the Cache Creek portion of Lake County. The Water Action Plan is developing a new water management approach based on updated information on land uses, cropping patterns, water use data, and economic growth. Specifically, the present study is looking at expected population growth, the effect of water prices on demand, the practical effect of conservation, the possible use of reclaimed water, and the needs of the Suisun Marsh. (Problems of the marsh are discussed in the article, "The Suisun Marsh: Its Future Depends on the Right Kind of Water," elsewhere in this issue.)

In the Russian River area, the issues are water demand and supply for Mendocino, Sonoma, and Marin Counties, and the Corps of Engineers' Warm Springs project. Repeated severe winter floods are a major problem in the area. What is needed is a clearer definition of water management concepts for the Russian River, including the potential for increasing the flow in the Eel River and the merits of enlarging Lake Mendocino.

In the South Bay-Central Coastal Area, waste water reclamation and water conservation measures are important, particularly as they relate to provisions of the State's position on the San Felipe Project. The Department of Water Resources withheld its support for funding for the project until such matters as the effect on water quality in the Delta, the use of reclaimed waste water, and local support for the project could be resolved. The Santa Clara Water District agreed to take less water from San Felipe in dry years and to make up the difference with treated waste water, and also to impose mandatory water conservation. This satisfied the Department's concerns. The Department will assist the district in developing water reclamation facilities.

The present overdrafting of ground water supplies is a matter of great concern in the east side of the San Joaquin Valley. More than 1 200 cubic hectometres (1 million acre-feet) of ground water is being withdrawn from storage every year than is being replaced. This deficit, if allowed to continue uncontrolled, will have enormous consequences to the local agricultural economy. The lowering of the water tables increases the cost and energy requirements to pump the water from the ground, causes the land surface to drop, and increases the salinity of the underground water by concentrating the salts present there. Unless remedial steps are taken, these problems can become even greater. Possible solutions include reducing water use, taking marginal land out of production, and importing more water to the area.

How to dispose of the highly saline drainage water that results from irrigation of agricultural lands is a problem along the west side of the San Joaquin Valley. The salty water is trapped by a layer of clay soils near the surface, reducing the fertility of the land. The Department, along with the U.S. Bureau of Reclamation and the State Water Resources Control Board, is considering several means of removing this waste water. Presently productive farmland will ultimately be ruined, if present conditions continue.

Significant water problems in San Luis Obispo and Santa Barbara Counties involve poor quality surface water, imbalanced distribution of surface water, and deteriorating quality of ground water. Local water districts have contracted to receive water from the State Water Project, when the Coastal Aqueduct is built. The Water Action Plan will study the timing for construction of this facility. One solution involves possible further development of local surface and ground water sources, particularly in San Luis Obispo County. Also, demand can be reduced by water conservation practices, and reclaimed waste water from urban areas may be usable to irrigate crops and to replenish the ground water basins.

On the basis of recent population forecasts and trends in industrial development, the South Coastal Area appears to have a supply of water that will be adequate until 2000. Present water problems relate to the deterioration of water quality in the Oxnard Plain, Upper and Lower Santa Ana Basins, and parts of San Diego County. Possibilities for improved water management include greater use of reclaimed water, more effective use of ground water, water exchanges, and reduction in demand through conservation.

Issues that apply to the Owens Valley-Mono County Area deal with reassessment of available and contracted-for water supplies, consideration of conservation, better use of surface and ground water, waste water reclamation, and possible water exchanges. Major items that are being examined include levels of Mono Lake, water needs of Owens Valley, and areas with a potential for developing greater instream use.

Water Project Operation and Other Studies

To achieve greater coordination among federal and State water projects and make more effective use of present water resources, the Water Action Plan is considering two additional subjects: water supply and instream water uses.

A key factor in the operation of any water project is maintaining a reserve to ensure that, when a drought develops, the project will continue to yield water. Heretofore, reserve supplies in California projects have been great enough to sustain yield through a dry period similar to the one that occurred from 1929 through 1934, which was the longest sustained drought in the Central Valley in the more than 120 years measured records have been kept. (Estimates of the probability of such a long-term drought occurring again range from one-in-100-years to one-in-400-years.)

Now we have the drought of 1976-77, which has thus far been the driest consecutive two years in California since rainfall measurement began in the middle 1800s. In much of the State, this drought is placing a more severe strain on water projects than would a repetition of conditions in 1929-34.

The Water Action Plan studies are examining the frequency of historical water shortages and will evaluate water project operating criteria and various ways of offsetting the risks brought about by these shortages.

Instream uses — uses of water within stream channels — is an important element of the Water Action Plan. The plan will include a series of pilot studies for selected rivers throughout the State to test whether a little more water in the rivers would lead to instream improvement. Just how much is "a little more water" and what constitutes improvement are questions that will be considered by a multidisciplinary team within the Departments of Water Resources, Fish and Game, Parks and Recreation, and Navigation and Ocean Development.

The current oil supply situation, environmental and social concerns about different sources of energy, and the economics of energy all make obvious that any realistic assessment of alternative ways of managing our water resources must consider energy impacts.

The Question of the Delta

Another program closely coordinated with the Water Action Plan has been the review of Delta alternatives. Since the Peripheral Canal concept was first recommended in 1965, several factors — increasing inflation, slowing population growth and the related buildup of water demand, and greater awareness of economic and environmental requirements for Delta protection — indicated that the concept needed to be reexamined under today's conditions.

The initial phases of study included public hearings and review of more than 20 alternatives identified by the Department. Additional options brought up during public discussion were also reviewed. The Delta alternative study sought to identify a specific course of action to satisfy the water needs of the State that depend on the Sacramento-San Joaquin Delta and, at the same time, protect the Delta environment. Selected elements of this course of action are wide-ranging. They include (1) a Peripheral Canal, (2) ground water storage programs in Southern California and the San Joaquin Valley, (3) a waste water reclamation program; (4) an extensive water conservation program; (5) an offstream storage project south of the Delta; (6) several storage projects north of the Delta, including Glenn Reservoir complex and the federally authorized Cottonwood Creek Project, and (7) a Mid-Valley Canal.

Another element of the plan is designed to protect the Delta. It includes environmental monitoring, a multiagency fish protection agreement, a Central Valley Project-State Water Project operating agreement, review of Delta water quality standards, obtaining federal authorization for Delta protection, south Delta water quality improvement, and protection for the Suisun Marsh.

Looking to the future, the Water Action Plan should serve California well, as the State presses forward in its search for the most beneficial ways of using and allocating its water resources.

An 11-member Water Advisory Panel assists the Department of Water Resources in carrying out the Water Action Plan. The panel is made up of individuals selected for their knowledge of water matters in the State and for their diversity of views on water problems and solutions. Its function is to review and assess the Department's planning efforts. The members are:

Harvey O. Banks, *former Director of the Department of Water Resources*

Ira J. Chrisman, *former Chairman of the California Water Commission*

Mary Ann Eriksen, *Southern California representative of the Sierra Club*

William R. Gianelli, *former Director of the Department of Water Resources*

Tom Graff, *Regional Counsel for the Environmental Defense Fund*

Larry E. Moss, *Executive Director of the Planning and Conservation League*

Robert J. Pafford, Jr., *resources consultant; retired Regional Director, Mid-Pacific Region, U.S. Bureau of Reclamation*

Bill Press, *Director of the State Office of Planning and Research*

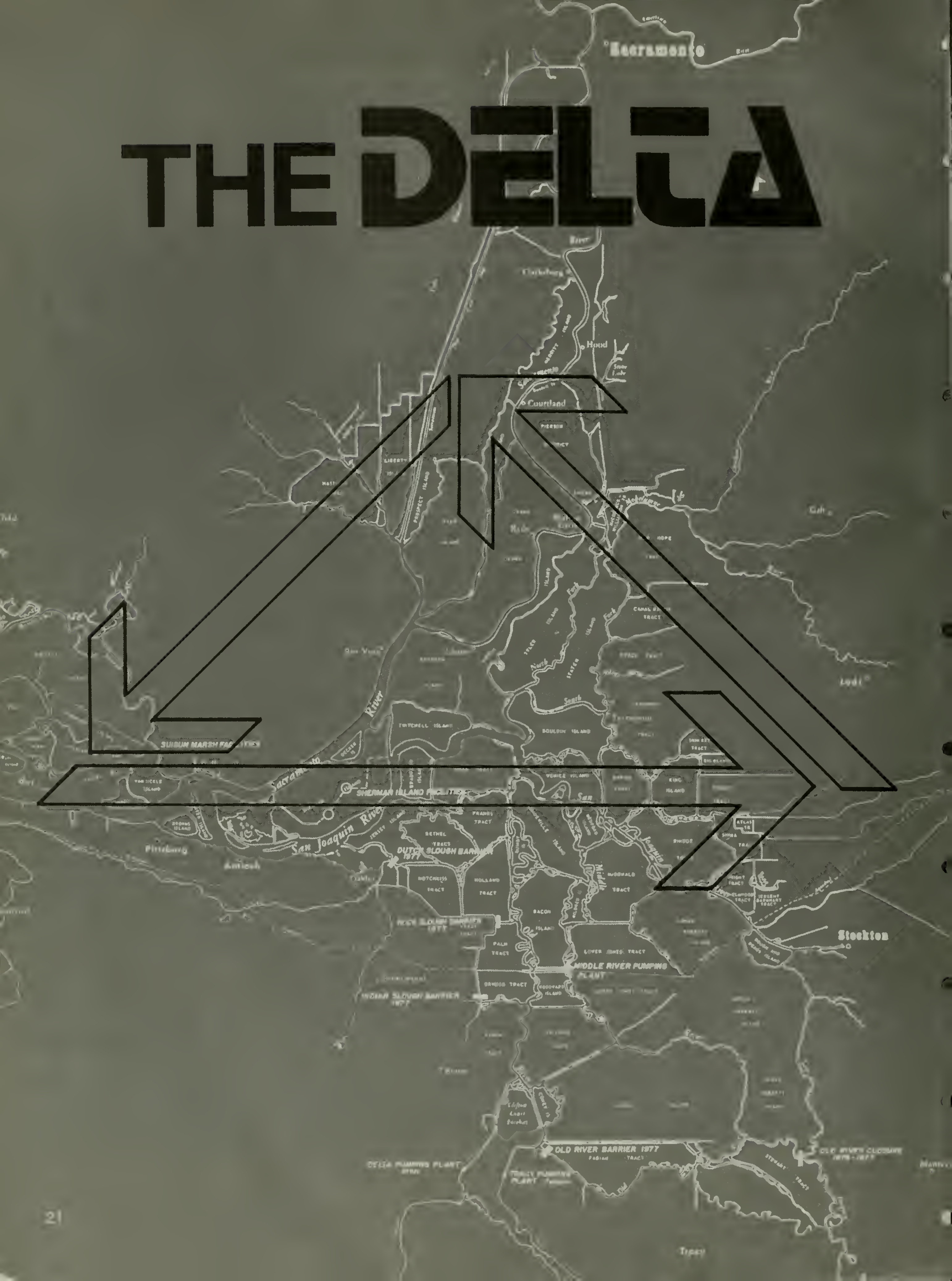
L. T. Wallace, *former Director of the State Department of Food and Agriculture*

William E. Warne, *former Director of the Department of Water Resources*

Several State and federal agencies concerned with management of water are also directly assisting DWR with the Water Action Plan. These include the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, the State Water Resources Control Board, the State Department of Fish and Game, and the State Department of Food and Agriculture.

Information for this article was contributed by Jerry D. Vayder, Supervising Engineer, Water Management and Hydrology Section, Sacramento.

THE DELTA



Sacramento
Clarksburg
Hood
Courtland
Lodi
SUISUN MARSH FACILITIES
SHERMAN ISLAND FACILITIES
Sacramento River
San Joaquin River
TWITCHELL ISLAND
BOULDIN ISLAND
Pittsburg
Antioch
DUTCH SLOUGH BARRIER 1977
HOTCHKISS TRACT
HOLLAND TRACT
BACON ISLAND
ROCK SLOUGH BARRIER 1977
PALM TRACT
MIDDLE RIVER PUMPING PLANT
INDIAN SLOUGH BARRIER 1977
Stockton
OLD RIVER BARRIER 1977
DELTA PUMPING PLANT
TRACY PUMPING PLANT
Tracy

1978 May Be the Year for Action in the Delta

The Sacramento-San Joaquin Delta, that vast maze of twisting waterways and broad, lush islands lying in the heart of California, is a unique region. No place quite like it exists anywhere else, here or in any other state in the country. Once a largely uninhabitable marshland periodically submerged beneath spring tides and winter floods, the Delta has been gradually withdrawn from the ocean's grasp to become one of the richest farming areas in the United States.

Viewed from the air, the Delta resembles a huge jigsaw puzzle, its pieces lying slightly apart. And, in a manner of speaking, the simile is pretty close to reality, because from the beginning of California's development, the region has been a giant puzzle whose solution has often baffled water planners. Even today, the Delta continues to be a source of controversy.

Water is a major key to the Delta's importance, water carried by its two great tributaries, the Sacramento and San Joaquin Rivers to supply towns, farms, industries, and recreation, and to serve as a source of export by the State Water Project and the federal Central Valley Project. All these uses compete with one another.

The area is a fertile island farmland that each year produces bountiful crops of corn, asparagus, pears, tomatoes, safflower, and alfalfa. It also provides food and cover for more than 100 species of wildlife and waterfowl, a setting for various recreational pursuits — chiefly boating and fishing, habitat for a flourishing fishery of more than a dozen species of game fish, channels for commercial shipping, sites of many industrial plants, and an important well field producing high-quality natural gas. Both the SWP and CVP have long-term contracts with dozens of public agencies that supply water to much of California's population, including 250,000 residents of Contra Costa County who receive their water directly from the Delta through the Contra Costa Canal. Taken altogether, the Delta contributes generously to California — economically and environmentally.

The Delta region is lightly populated, compared with the adjacent San Francisco Bay area and the environs of the City of Sacramento, but several picturesque and historic small communities are situated on the banks of the Sacramento River near the Delta's western boundary — towns such as Clarksburg, Walnut Grove, Freeport, Hood, Courtland, Isleton, Locke, and Rio Vista, several of which date back to settlement in the last century.

Although it lies some distance inland — some 72 kilometres (45 miles) northeast of the entrance to San Francisco Bay, the Delta is situated at sea level and is open to the ocean's tides. To those who spend leisure hours boating and fishing there, the Delta can seem a world apart. The meander of the channels, the slow-moving water, and the quiet and sense of seclusion create a restful setting. At low tide, the levees, covered with plant growth, rise many feet above the water, screening the islands from view. Every turn of a channel presents a new vista. At high tide, the scene changes somewhat because the tops of some levees are only inches from the water surface. Those who farm in the Delta have an entirely different view, however. From the islands, no water is visible. The levees that bound them completely rise 4½ to 9 metres (15 to 30 feet) above the land.

Early explorers ventured into the Delta first in 1808, but the Delta's real growth began with the brief but feverish era in California's history when the search for gold dominated the scene. Almost from the outset of the Gold Rush, disillusioned miners returning from the Sierra Nevada gold fields found conditions along the river margins and Delta channels favorable for raising certain foodstuffs that were then in short supply.

By the early 1850s, a few farm families were settled on natural levees along the Sacramento River in the northern Delta, and small fields were being tilled and cultivated on scattered sites that rose a little above the surrounding land. But, for the most part, settlement of the rest of the region was slow in coming. In those early days, the Delta's principal value was serving as a means of reaching Sacramento, Stockton, and other river and Delta settlements by water. The major waterways were in heavy use for a few years for travel and shipping.

Starting in the 1860s, the Delta began to suffer enormous damage from the vast amounts of debris that were being swept downstream from hydraulic mining sites far up the Sacramento and the San Joaquin. Hundreds of millions of cubic metres (cubic yards) of mine tailings moved through the Delta for several decades, even after mining operations were halted by a permanent injunction issued by a federal court in 1884. Silt filled the river channels and adjoining sloughs, altering the navigable channels and greatly hindering shipping activity, particularly in the Sacramento River. This, plus frequent winter high water and occasional very high tides, caused many Delta islands to flood periodically. Individual efforts to build levees to protect them from high river flows and high tides began as early as 1852, but these failed short of their purpose.

Organized attempts to reclaim the marsh and overflowed lands of the Delta began in the 1860s with the formation of the first reclamation districts. Levees developed from early low, continuous earth mounds to later massive embankments, as much as 30 metres (100 feet) wide at the base of 9 metres (30 feet) high. Levee building was essentially completed in the 1920s. Since then, the biggest task has been keeping the levees in sound condition so that people and lands are safeguarded from flooding.

In 1878, residents asked the State of California to bring its authority to bear on the mining debris problem, and there followed the creation of the office of State Engineer, the first in a long and continuing series of steps by government to correct Delta deficiencies. Attempts to sort out and solve Delta problems have continued under government guidance because of the need for coordinated overall planning.

The Delta's network of levees that enclose each island and tract are the mainstay of its existence. They make the region what it is today. Extending for more than 1 120 kilometres (700 miles), these earthen embankments protect land lying as much as 7½ metres (25 feet) below water level.

Whatever affects the Delta, in one way or another tends to influence much of our total water resource. The reverse is also true. Whatever affects water elsewhere in the State, sooner or later is felt in the Delta. This has never been more apparent than in 1977, when California was short on water and long on perplexing water issues. Some of the most difficult of these centered on the Delta. Probably one of the biggest stumbling blocks to resolution of the tangle of Delta problems is the enormous complexity of the issues involved and the manner in which each ties in tightly with another. This is the case, whether it is a matter of preserving the fishery, maintaining a usable supply of water for Delta farms and industries, or making certain of enough good quality water to meet delivery commitments to contracting water agencies elsewhere in California. Solving one problem depends on solving some others. Another factor is the multiplicity of interests and overlapping jurisdictions — federal, State, county, regional, local, and private. Dozens of organizations have a stake in the prosperity of the Delta. There is good reason for saying that planning for the Delta is a challenge.

One of the most serious and immediate difficulties concerns migratory fish. Water from Shasta, Oroville, and Folsom Reservoirs to the north flows through the Delta and is pumped from its southern edge by the Central Valley Project and the State Water Project for use in Contra Costa County and in Central and Southern California. When the pumps operate at full capacity during low summertime flows, the pull they exert is so strong, the natural flow of water westward toward San Francisco Bay is actually reversed in some places. Salmon and possibly other species which instinctively swim against the current to spawn in the Delta and the Sacramento and San Joaquin Rivers become confused and lose their way. Their difficulties will worsen as Delta diversions for the CVP and SWP increase in the years ahead, unless corrective action is taken to move water across the region in an isolated structure. The more water that is withdrawn, the more serious the position of the fish will be.

These pumps also present another dilemma because, as they take in water, they also draw young fish, fish eggs, and larvae toward them and many of these are carried south down the CVP's Delta-Mendota Canal and the SWP's California Aqueduct. Screens at the pumping plants successfully salvage adult fish that can swim well, but they cannot presently stop young fish, eggs, and larvae. The situation is especially critical for eggs and larvae of the striped bass, the principal game fish in the Delta.

A further problem for Delta fish is the water's level of salinity and relative clarity. The *Neomysis* shrimp, a tiny organism that is the chief item in the diet of striped bass, are extremely sensitive to both salt and light. If the salt content of the water is not just right and the amount of silt suspended in the water is inadequate to block out sunlight, the numbers of shrimp decline. These small creatures are also adversely affected by the suction of the pumps.

As the rate of pumping in the southern Delta by the CVP and the SWP is stepped up from year to year, another factor enters the picture: the disturbance of the Sacramento River and some Delta channels by the increasing pull of the pumps. The water will move faster and faster, scouring some channel bottoms and underwater slopes. These actions are unavoidable, unless measures are taken to avert them, because the operating plans of both State and federal projects are based on transporting greater amounts of water each year for many years, and the Delta is the only course this water can presently follow.

The damage to fish, and channels are problems that have come about because the State Water Project is actually incomplete. The project is intended to provide facilities for directing SWP water to the pumps without damaging the Delta. Completing the State Water Project by building a Delta water transfer facility will alleviate these problems.

Other problems whose solutions are not related to such a facility include the industrial water pollutants that endanger the Delta's future, particularly those introduced by petrochemical, paper products, and food processing plants operating largely on the coast of Contra Costa County just west of the Delta proper. The State Water Resources Control Board and the Regional Water Quality Control Boards exercise constant vigilance to offset their effects on water quality.

The condition of the levees is an ever-present source of concern to the Delta. The early levees were constructed of the light, fibrous peat soils native to the Delta, which crumble easily to a powdery substance. Later they were built from sand and fine-grained silt dredged from the river bottom. Seepage into adjacent island farmlands is a recurring problem. The old peat foundations are now compressed under the weight of the masses of earth above them. Many levees are in poor condition, urgently in need of costly rebuilding and strengthening. Ownership and maintenance of many of them is in private hands. Others are maintained to federal and State standards and are inspected every year to make certain they are safe. Recent court action has indicated that in the future the State of California may be held responsible for supervision of levee maintenance throughout the Delta.

Levees are under continuous assault by wind and waves. The most feared events in the Delta are prolonged high river flows, a strong south wind, and a high tide, all typical of the region. When these three events occur together, the islands are in serious jeopardy. Levee failures are not uncommon. Entire tracts and islands have been inundated at various times — at least 40 of them since 1900 — disrupting the lives and livelihood of the residents. Most of the flooded land has since been reclaimed. The most recent of these events was the Brannan-Andrus Islands flood in June 1972, which took place when a levee broke and water covered a large area, including part of the town of Isleton. This took place at a time when the flow in the river was low.

Flooding of the Delta islands in the early days of settlement was not as serious as such events are now. The land was much higher when the region was first being settled, and when an island was overrun with flood water, the residents had only to open the tide gates and wait for the water to drain back into the channels. Since then however, the islands have been intensively developed for agriculture, thus greatly altering the face of the land. Over the years, the land has been gradually settling, chiefly because the peat soil that comprises many of the islands is constantly decomposing and compacting under the pressure of heavy agricultural machinery. When its surface is disturbed by cultivation, the fine, light soil is lifted and carried off by the wind. In some places, the island's surfaces have subsided as much as 7½ metres (25 feet) below water level, and when the land is flooded, the water must now be removed by pumping, a costly and time-consuming procedure.

Protecting the Delta from the influence of salt water is a task of monumental proportions that must continue unabated year-round, especially in periods of low river flows. The present drought, which is causing great difficulties in the Delta, brings to mind earlier dry years 1924 and 1928-1934, when the Delta suffered from the effects of another dry period. Flows were extremely low in the Sacramento and San Joaquin Rivers, and salt water from San Francisco Bay was able to travel north nearly to the town of Hood, infiltrate throughout the Delta, and reach Stockton. During late summer and early fall in those drought years, channel water was often too salty for irrigation, and farmers had to curtail watering and alter their planting patterns. Water for livestock and households was hauled to some central Delta islands. These remedies were particularly characteristic of 1924 and 1931, years of extreme water salinity.

However, our current water-short condition is focusing attention on the Delta's status as never before in our history. Although the three large Northern California reservoirs, Shasta, Oroville, and Folsom, built since the previous drought period, have provided the tremendous flows of fresh water needed to keep ocean salt water out of the rivers and the Delta channels, storage in these reservoirs is at an all-time low point and salt-water penetration remains an ever-present threat. The salt impairs crops, domestic supplies, and industries. It can change the entire environment of the Delta, creating a highly unfavorable habitat for freshwater fish and wildlife.

In attempts to moderate the effects of the drought during the past two years of declining river flow, DWR has erected temporary rock dams at several key points in the Delta to redirect the flow of water in the channels. The first barrier was built in late August 1976 at the entrance of Sutter Slough on the Sacramento River to force more water to pass down the river and move through the central Delta. The rocks were removed on October 10 when the river's flow dropped.

Early in 1977, other barriers were placed to improve the quality of irrigation water and to better serve residents and industries in Contra Costa County. One dam was installed in Rock Slough south of Bethel Island and another in Indian Slough east of the town of Brentwood. These were necessary to reduce the water's salt content, which was twice the normal level. They forced fresher water toward the intake of the Contra Costa Canal. Without the barriers, quality standards for the canal could only have been met by releasing more water from upstream reservoirs, a highly undesirable move during a drought.

A water-saving rock barrier was installed in September 1977 across Dutch Slough about five miles east of Antioch. DWR plans to remove it as soon as the drought emergency has ended. The dam is preventing the inflow of salt water and making it possible to hold salt content at an acceptable level with smaller upstream reservoir releases. Old River was closed for a time in both 1976 and 1977. If the drought continues, other temporary closures may be necessary.

The "San Carlos," DWR's floating laboratory, which is equipped to collect samples of water in Delta channels and make on-board analyses of its quality

As useful as these barriers are, they are solely short-term responses to an emergency. Far-reaching solutions to the Delta's problems lie in an entirely different direction.

In 1965, after extensive study, and with widespread public support, the State and federal governments settled on a project called the Peripheral Canal as the best means of protecting and improving the fishery and the water, at the same time meeting water quality requirements of the State and federal projects. The 67-kilometre (42-mile) canal was proposed to divert Sacramento River water around the eastern edge of the Delta to CVP and SWP pumping plants on the southern edge and to release water to the Delta at several river crossings enroute to the pumps.

In 1974, DWR released a draft environmental impact report on the canal that raised a lot of questions and generated a lot of controversy. In the 10 years that had then passed since the Peripheral Canal was first recommended, conditions in California had changed dramatically. Inflation had continued at a high rate, a slowing population growth had reduced the growth of demand for water, and the public had become more aware of the need to protect the Delta's environment. As a result, in 1975 DWR called for a complete reappraisal of alternative possibilities for the Delta under these altered conditions.

This new examination was aimed at doing much more than simply reviewing various physical facilities. The whole point was to put together a package of actions that would be environmentally responsible and, at the same time, answer the need for good quality water in the Delta and other parts of the State. This approach meant exploring all actions, from one end of California to the other, that could affect the Delta.

After a year and a half of intensive examination, during which nearly 40 alternative courses of action were studied, early in 1977 DWR again concluded that building the Peripheral Canal was the best possible answer. This time, however, the canal was proposed as only one element of a comprehensive water development package that included a program of dams, reservoirs, canals, and other facilities north and south of the Delta and a host of institutional measures designed to provide the guarantees needed to protect the Delta — State and federal legislation and interagency agreements on fish management, water project operation, and project financing.

The DWR study showed that enough water can be delivered to the Delta and to both the State Water Project and the Central Valley Project until 2000, if we carefully stretch our existing supplies and if we develop some additional sources of water, both traditional and nontraditional. In wet years, excess water could be diverted from the Delta and stored in surface and underground reservoirs south of the Delta. Then, in dry years, this water could be taken from these reservoirs, reducing withdrawals from the Delta.

As envisioned by DWR, the Peripheral Canal would completely eliminate reverse flows in the Delta channels, considerably easing conditions for fish. However, despite the diversion of some water to the canal, large quantities of water will still flow past the canal intake on the Sacramento River and down into the Delta and San Francisco Bay. Moreover, because the canal would be a closed system, water for project export would be isolated from the channels, and fresh water for the Delta would be released as needed at a dozen points along it to enhance water quality. These releases would regulate the quality and assure positive downstream flows in the direction of San Francisco Bay. Some opponents of the canal fear that in some future drought a political decision might be made to shut off the outlets and ship all the good quality Northern California water past the Delta, leaving the region mired in intolerably salty ocean water. However, State laws prohibit this type of action. Furthermore, federal laws and water supply contracts with Delta agencies will contain additional assurances of Delta protection.

Without a facility to carry some of the Northern California water around the Delta, water service agencies that contract to purchase water from the SWP and CVP will face increasing risk of shortages of water during dry periods. Moreover, the quality of the water that will be available will be seriously jeopardized. With the canal, the contracting agencies will receive water of better quality. To function to the greatest possible good, the canal concept must include three points: amounts of export water must be limited, fish screens must be well designed and operated, and firm guarantees must be obtained to protect the Delta, the Bay, Suisun Marsh, and the North Coast environments.

In February 1977, Senator Ruben Ayala, Chairman of the Senate Agricultural and Water Resources Committee, introduced Senate Bill 346 in an effort to end the stalemate over the construction of the Peripheral Canal. An amended version of SB 346 was created in the spring, when a coalition of water, environmental, industrial, farm, and labor interests agreed on several amendments to the bill. For the first time in history, the canal had the support of the Sierra Club, the Planning and Conservation League, and the North Delta Water Agency.

SB 346 was adopted by the Senate in June and by the Assembly in September, in both instances after undergoing amendments that made changes in its provisions. It was returned to the Senate for concurrence with the Assembly's amendments and fell short of approval just before the Legislature adjourned for the year. SB 346 has now become a two-year bill and has been referred to a joint conference committee made up of three members from each house. The committee will hold interim hearings and will report back with its recommendations when the Legislature resumes in January 1978.

The scope of SB 346 is far-reaching. As it reads now, the bill provides for the construction of extensive physical facilities to develop water in three areas — north of the Delta, south of the Delta, and in the Delta itself. The Delta works include the Peripheral Canal, fish protection facilities, relocation of the Contra Costa Canal Intake, water quality improvement facilities, and permanent protection for Suisun Marsh. North of the Delta, three large water storage structures are authorized: the Cottonwood creek Project, the Glenn Reservoir, and the Colusa Reservoir. (Colusa Reservoir is an alternative to Glenn Reservoir.) These are planned to provide in-stream and off-stream storage in Sacramento Valley. South of the Delta there are several features intended for water conservation, waste water reclamation, development of storage for ground water, off-stream reservoir storage (Los Vaqueros Reservoir or Los Banos Reservoir), and a large canal (the Mid-Valley) to transport water to the east side of San Joaquin Valley to reduce ground water overdraft there.

Legal and institutional provisions of enormous significance to the future of water development and use in California are contained in the present version of Senate Bill 346. These revolve around the role of the United States government in the plan. The

bill requires that before building can begin on the Peripheral Canal, the Contra Costa Canal Intake relocation, or the Mid-Valley Canal, the federal government must fulfill important provisions, among them coordinating operation of the Central Valley Project with that of the State Water Project, sharing the cost of building the Peripheral Canal, and entering into agreements on water quality and water supply with Delta and Suisun Marsh water agencies.

The provisions governing federal participation in the Delta hinge on the physical inseparability of the State and federal water projects. Both supply water to the Delta, both take water from it, and both have an important stake in protecting the Delta from salt-water intrusion. However, each project operator — the Department of Water Resources and the U.S. Bureau of Reclamation — views its Delta obligations differently. DWR must, under California law and federal law, meet standards set by the State Water Resources Control Board and the Federal Water Pollution Control Act. This means that enough water must be released from upstream reservoirs to prevent salt water from entering the Delta. Operation of the State Water Project is based on these requirements.

DWR maintains that State and federal law requires the CVP to conform to the same water quality standards as the State. The Bureau, on the other hand, takes the position that the CVP is not subject to State law and that federal water quality laws do not apply to salinity intrusion. It maintains that its authority is limited to meeting its contractual commitments to provide enough water of adequate quality at the CVP pumps in the southern Delta. The Bureau has stated that it does feel an obligation to meet agricultural water quality standards in the Delta and, further, that it will also allot water to benefit fish and wildlife, if surplus water is available for that purpose.

By operating in accordance with its views, the Bureau has, at times, failed to fully provide its share of water needed to protect the Delta during the present drought. This has placed an extra burden on the State Water Project, which has released additional water to keep salinity levels down. However, since June 1977, when the State Water Resources Control Board modified its standards, the Bureau has fulfilled its share in meeting those lower Delta water requirements.

Congressional action will be needed to resolve the situation. Some of the provisions of SB 346 call for the enactment of federal legislation that will require the Bureau to maintain the same water quality in the Delta as the State and will provide for an agreement to protect fish and wildlife. Such legislation will have to be passed before the Peripheral Canal can be built.

State law says that both DWR and the Bureau must meet Delta quality standards. The bone of contention is the extent to which federal law applies to the Bureau's operations. The matter is now moving through the courts. The Ninth Circuit Court of Appeal (in the case of United States *vs.* California) decided against the State, which is now appealing to the U.S. Supreme Court.

As a vital segment of Senate Bill 346, the Peripheral Canal will benfit the Delta and other parts of the State in many important ways. It will return nearly all Delta tributary streams to normal downstream flow. It will transport only water for export that is not needed by the Delta, which will mean more efficient use of the great winter flows that pass through the region in most years. It will moderate the channel scour and fishery impairment now being caused by the direct pull of the SWP and CVP pumps. At present, fish tend to live in the western and central Delta because the dead-end sloughs in the eastern Delta are short of oxygen. With the canal, the fish are expected to move into eastern channels, making the entire Delta a nursery for fish.

The canal will save water by more efficiently moving water to pumps of the SWP and the CVP. This savings can amount to as much as 1 233 500 cubic hectometres (1 million acre-feet) of additional water the projects can export from the Delta. The canal will provide abundant opportunities for outdoor recreation where few are now available. Its wide, fully landscaped banks and deep, slow-moving water will furnish settings for swimming, fishing, boating, hiking, water-skiing, bike riding, picnicking, and horseriding.

The Peripheral Canal will not solve all the Delta's problems, of course, but with the enactment of SB 346 and follow-up congressional legislation, it will ultimately alleviate many of the most serious ones. Full federal participation is critical to the success of the plan, as well as firm commitments to meet water quality standards and achieve truly coordinated operation of the State Water Project and the Central Valley Project, and clear agreement on fishery management between federal and State agencies.

Perhaps, after all, 1978 will go into the books as the year California began to make solid progress in solving the problems of the Delta.

Information for this article was contributed by Walter H. Fisher, Water Resources Engineering Associate, Central District Office, Sacramento; and John O. McClurg, Senior Engineer, Water Resources, Delta Alternatives Study Program, Sacramento

Recent DWR publications of interest to those who want to learn more about the Delta include:

Bulletin No. 192, "Plan for Improvement of the Delta Levees," May 1975. Free.

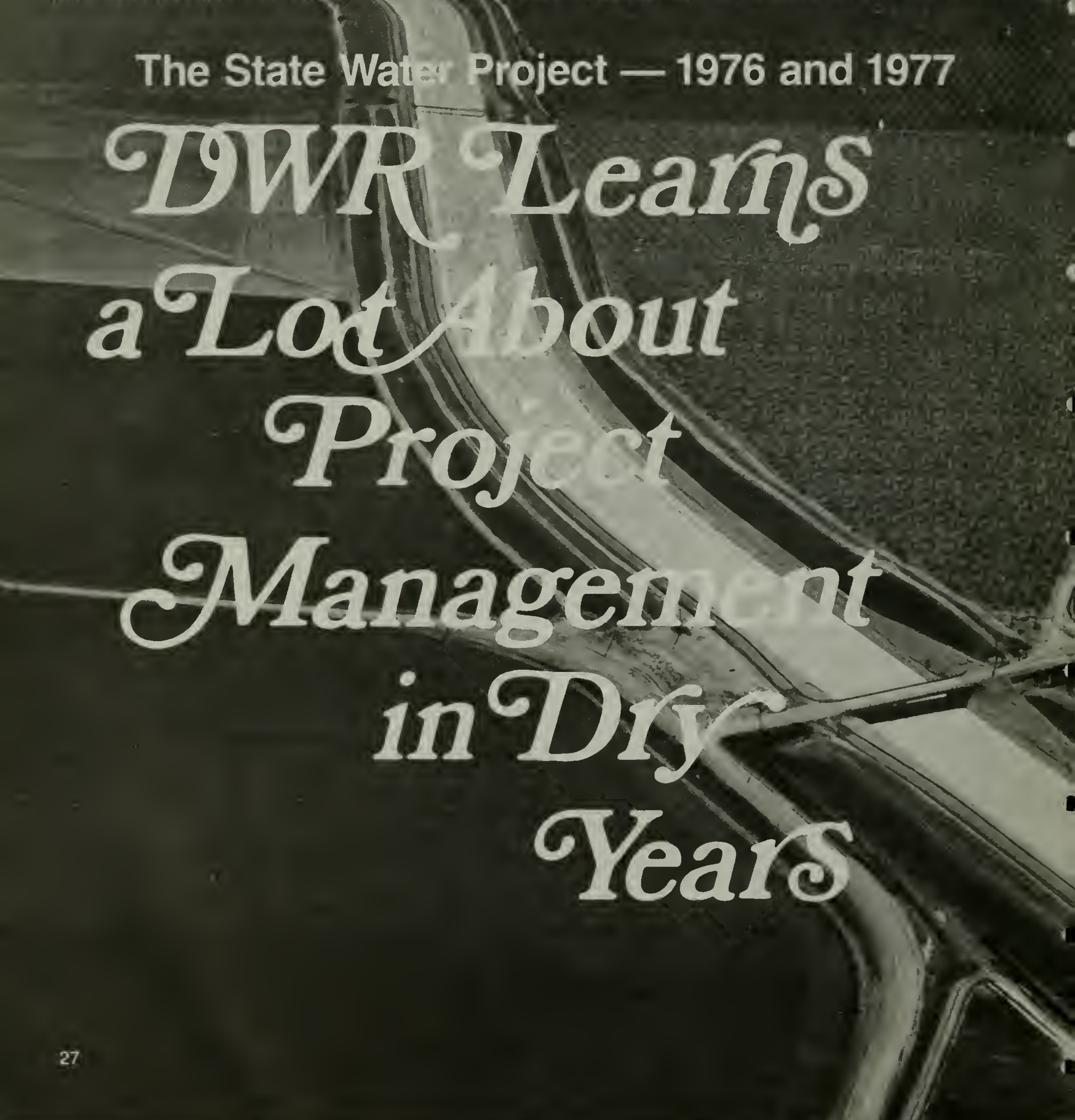
"Key Elements — SB 346," November 1977. Free. Presents the major points in Senate Bill 346, including maps showing sites of facilities.

"Water for California" (brochure), November 1977. Free.

California's water supply fluctuates widely. Wet years, dry years, and in-between years succeed one another in an unpredictable pattern, and rainfall in a wet year (such as 1973-74) may be five times that in a dry one. Furthermore, the rain and snow season usually lasts, off and on, from about November through April, but some years, more than half the precipitation has fallen between February and May.

Another factor is the well-known geographic disparity between the region of greatest precipitation and the region of greatest water use. About 70 percent of the State's water consumption occurs south of Sacramento, while about 80 percent of the precipitation falls north of the city. To remedy nature's oversight, major transbasin water systems such as the State Water Project have been built to redistribute water where it is needed, when it is needed.

The period between the fall of 1975 to the fall of 1977 has been the driest two-year period recorded in California, and this has severely tested the project's ability to respond to greatly reduced water supply conditions. It also emphasized the effects of various legal and physical constraints on the project. The design of the State Water Project was based on all types of water years — ranging from very wet to very dry. The designers took as the bottom line the drought period of 1928-1934. Moreover, in the few years the project has been operating, some years of below-normal rainfall have occurred, but 1976 and 1977 have



The State Water Project — 1976 and 1977

DWR Learns a Lot About Project Management in Dry Years

been a new experience. Because not everything happened as had been anticipated, the Department of Water Resources (DWR), as operator of the project, was to learn a great deal as the two-year dry period progressed.

When the 1975-76 water year began in October 1975, the water supply situation appeared good. Rainfall in October was well above average, and runoff from the Sacramento Valley was generally satisfactory through December. Outflow from the Delta was high enough to permit diversions to meet the project's contractual commitments and to refill San Luis Reservoir in Merced County, the project's major offstream storage facility.

For the rest of the 1975-76 water year (to the end of September 1975), most of California was to receive less than normal precipitation, with the greatest shortage occurring across the center of the State. For the major streams that are tributaries to the Sacramento-San Joaquin River Delta, this year resulted in the fifth lowest amount of recorded runoff.

Unfortunately, precipitation and resulting runoff in the winter of 1976-77 was substantially lower than 1975-76 runoff. Precipitation amounts varied from one-third to one-half of normal for most of the State. Runoff in Northern and Central California streams varied from 6 to 46 percent of normal, with many streams setting new records for the smallest amount of runoff.

The 1976-77 water (October 1 — September 30) proved to be the driest since detailed records of precipitation and runoff began.

Features of State Water Project

A brief description of the State Water Project will help explain the obstacles that confronted the Department of Water Resources during 1976 and 1977.

The project is a giant water transport system made up of a series of storage and regulating reservoirs and three facilities for transporting the water — the North Bay Aqueduct, the South Bay Aqueduct, and the California Aqueduct. The principal conservation facility is Lake Oroville, which is located on the Feather River. It will hold up to about 4 300 cubic hectometres (3½ million acre-feet) of water. The California Aqueduct begins in the southern Delta near Tracy and takes SWP water 715 kilometres (444 miles) south, ending at Lake Perris in Riverside County. In the course of this journey, the water is lifted by several pumping plants. Four reservoirs in Southern California — Pyramid, Castaic, Silverwood, and Perris — provide regulatory and terminal storage. San Luis Reservoir, near the town of Los Banos on the west side of San Joaquin Valley, is an extremely important feature of the project. It can store 2 590 cubic hectometres (2.1 million acre-feet) of water for both the State Water Project and the federal Central Valley Project (CVP).

The Delta is the focal point for diverting water to the California Aqueduct and, for that matter, to the Central Valley Project, operated by the U.S. Bureau of Reclamation. It was the key to operation of the State Water Project during 1976 and 1977. Most of the water available to the SWP passes through the Delta. Its many miles of waterways are fed by the Sacramento and San Joaquin Rivers, the major streams draining the Sacramento and San Joaquin Valleys. The Sacramento is the larger of the two streams. It brings 80 percent of the total streamflow to the Delta. Some of the Sacramento's flow is regulated by Shasta Dam, a CVP facility that controls the river north of Redding; some by Oroville Dam, a SWP facility that controls the Feather River; and some by Folsom Dam, a CVP facility that controls the American River.

North of the Delta, water is taken from the Sacramento River at many points, chiefly for farmlands irrigation. Once it reaches the Delta, the water is tapped for agricultural, municipal, and industrial uses, and some of the water evaporates from the water surface. These Delta uses, added together, are called channel depletions.

The hydraulic characteristics of the Delta mean that much of the water must pass down the Sacramento River, around Sherman Island, up the San Joaquin River, and then into the southern Delta, where it flows through numerous channels to the point of diversion. To protect the quality of this water, some of it must flow west toward Chipps Island to hold out saline water entering from Suisun Bay. This outflow varies with tides, winds, atmospheric pressure, and other factors. While its size varies from time to time, outflow under normal conditions generally must average about 113 cubic metres per second (4,000 cubic feet per second) to maintain quality standards.

The outflow from the Delta cannot be measured directly. An estimate called the Delta outflow index has been developed, involving the difference between inflow to the Delta and the sum of channel depletions and exports. Although the Delta outflow index is a valid tool in most years, it still only approximates the seaward Delta flow and can sometimes be quite misleading, as events during this two-year dry period were to show rather dramatically. For example, the value assigned to channel depletions represents normal conditions, but in a drought period like 1976 and 1977, conditions were anything but normal. Many times the channel depletion value suggested that little, if any, water was being used in the Delta, when in fact widespread irrigation was clearly visible. As a result, less water was flowing from the Delta than the index indicated. This discrepancy, and an inability to predict it, made operation of the State Water Project extremely difficult.

Factors in Operations Planning

Because some of the features of the State Water Project and the Central Valley Project overlap, so to speak, their operations are necessarily mutually interdependent. Releases from CVP and SWP reservoirs meet in the Sacramento River and mingle in the Delta. The objectives and activities of the U.S. Bureau of Reclamation, operator of the CVP, and the Department of Water Resources must therefore be closely and carefully coordinated. Both agencies operate in accordance with a document called the Coordination Operating Agreement, which establishes the guidelines for sharing water, including the water needed to achieve water quality standards.

An important factor in DWR's operations planning is the rapidity with which the State Water Project — and the Central Valley Project — can respond to various methods of operation in the Delta. An almost immediate response is brought about by increasing or decreasing Delta diversions at either or both of the SWP and CVP pumping plants just south of the Delta. Releases of greater or lesser amounts of water from the three large Sacramento Valley reservoirs take a little longer. A change at Folsom Lake is effective in one day; at Lake Oroville, two days; and at Shasta Lake, five days. It was because of this time lag that inability to predict the Delta outflow index was critical.

Water rights decisions and water quality basin plans approved by the State Water Resources Control Board govern the quality of water supplies in the Delta and place stringent limits on the State Water Project. These standards are designed to protect the Delta. They constrain the ability of the project to divert water, but, as a practical matter, they also protect the quality of these diversions.

Operational Problems

The first sign of impending trouble due to the drought appeared near the end of January 1976, when the Delta outflow index dropped to about 142 cubic metres per second (5,000 cubic feet per second). A balanced condition (as defined in the operating agreement) was declared, marking the beginning of a careful coordination of various facilities to control the index and thus protect the Delta and yet provide, to the maximum possible extent, water for export by both State and federal projects.

One of the Delta quality standards encountered early each spring involves salinity limits in the San Joaquin River for protecting spawning striped bass. When this limit was exceeded in late March 1976, the State Water Project reduced exports from the Delta and increased releases from Oroville Reservoir to meet this standard. This problem continued in 1977.

Protection of striped bass is also covered in an agreement between DWR and the Department of Fish and Game (DFG). Under it, DWR curtails exports from the Delta to the greatest possible extent for five weeks, primarily through April, each year. In 1976, DWR complied with a request by DFG to begin in late May, instead. Near the end of the five weeks, extensive repair of the California Aqueduct in Stanislaus County meant that Delta diversions had to be reduced until the middle of August. Commitments to deliver water to San Joaquin Valley farmers and to Southern California customers of the project were met by releasing water from San Luis Reservoir and with some water supplied by the Central Valley Project. In 1977, Delta diversions were being cut back so severely that this five-week curtailment was not a factor.

Whenever salinity in the Delta passes a certain level, the Water Resources Control Board, through a water rights permit, prohibits the State Water Project from storing water in its upstream reservoirs and from exporting natural Delta inflow in April, May, and June. In both 1976 and 1977, efforts by the Department of Water Resources to stay within the required limit failed during most of the three-month period. As a result, DWR was unable to store water in both Oroville and San Luis Reservoirs, water that could have been used later.

The inability to accurately forecast amounts of water that would be used in the Sacramento Valley — particularly in April, May, and June — caused considerable concern for both DWR and the Bureau of Reclamation. In substance, far more water was taken from the Sacramento River between the points of reservoir release and the Delta than normal. As a result, the State Water Project was forced to take much more water from Lake Oroville than was customary.

Operation of the California Aqueduct is based on delivery of entitlements (amounts of SWP water to which contracting agencies are entitled by contract with DWR) plus delivery of what is called surplus water. This is water over and above the amounts of the contract entitlements that, if available, can be delivered by the aqueduct. This water can be accommodated because the SWP is not yet operating at its full capacity.

In 1976, the impact of the drought on reservoir storage carried over to meet 1977 demands meant that DWR had to restrict deliveries of surplus water, principally in the San Joaquin Valley. Requests for this water in December 1975 totalled about 863 cubic hectometres (700,000 acre-feet), later to be increased to more than 1 110 cubic hectometres (900,000 acre-feet). Prudent operation at that time called for reserving water to carry over into 1977, in the event that 1977 runoff equalled that which occurred in 1934, a very dry year. To accomplish this, deliveries of surplus water were cut back to about 60 percent of the amount asked for.

Temperatures in August and September were low, so about 25 cubic hectometres (20,000 acre-feet) of additional water was provided to meet particular problems, principally to orchard or vineyard operators.

Unfortunately, the record low amounts of runoff in 1977 in most river basins further reduced the water stored in most California reservoirs. Reservoir storage carried over from 1976 had been intended to provide sufficient water to at least make entitlement deliveries to the State Water Project contractors in 1977. This plan was based on the assumption that water supply in the winter of 1976-77 would at least equal that of 1934. As the months went by, it became apparent that there would not be enough water to provide even these quantities. DWR then had to cut entitlement deliveries to agricultural water users by 60 percent and municipal and industrial users by 10 percent. Project contractors received only about 69 percent of the water they would otherwise have gotten.

Efforts to Alleviate the Effects of the Drought

As 1977 progressed, and it became clear that inflow to the Delta would be at an all-time low, it was also clear that meeting existing water quality standards would be very difficult, if not impossible. As a result, the Water Resources Control Board was asked to modify the Delta standards. The first modification, issued in February, required less Delta outflow when project deliveries are curtailed. The second, issued in June, established drought emergency regulations for conserving limited water supplies upstream from the Delta. The water saved as a result of these two modifications is to remain in storage in upstream reservoirs of the State Water Project and Central Valley Project and in San Luis Reservoir.

The Department of Water Resources must, by law, meet the Water Resources Control Board's requirements. However, the Bureau of Reclamation does not consider these standards a legal obligation and operates the Central Valley Project according to its own operating policy and water quality objectives. These objectives generally required less Delta outflow than did the Board's objectives in effect before the June 1977 changes. Therefore, from January to June 1977, the State Water Project released approximately 100 cubic hectometres (81,000 acre-feet) to compensate for the difference in required Delta outflow. Since June, DWR and USBR have been in agreement on the required outflow on all except three days in July.

As Delta water quality worsened in spring 1977, problems were developing for water users in and around the Delta. Cities and industries served by the Contra Costa Canal were the first to be affected. To improve the water delivered to them, rock bar-

Rock barrier on Dutch Slough under construction in 1977, with siphons being placed in position riers were constructed in Indian and Rock Sloughs and a pumping plant was installed at Middle River. This allowed the better water from Middle River to be transported to the Contra Costa Canal intake channel. Deliveries through this system began on June 10, 1977.

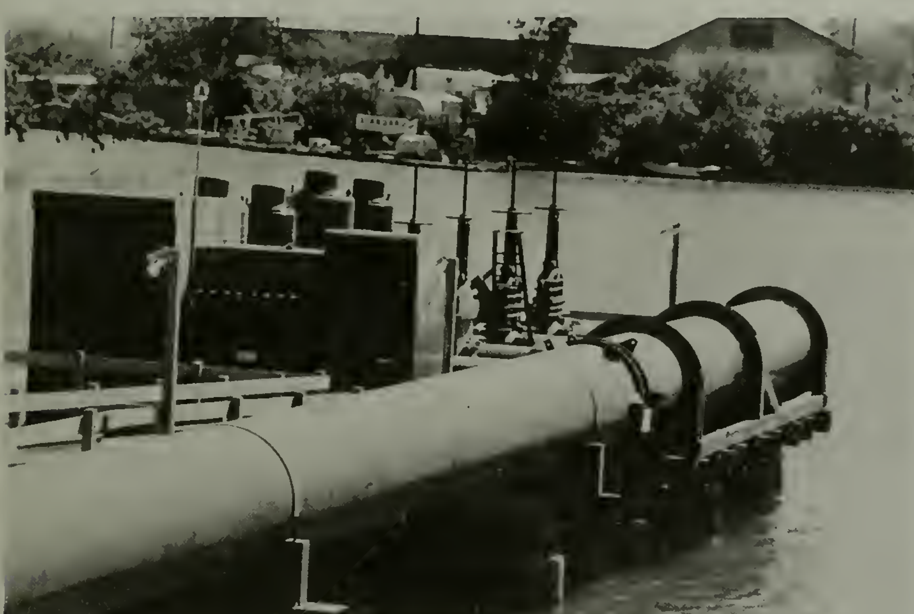
To ease the effect of the drought on agriculture and wildlife in the western Delta during 1977, DWR constructed facilities to provide better quality water to agriculture on Sherman Island and to wildlife habitat in the Suisun Marsh. Rock barriers were installed in the San Joaquin and Old Rivers in 1977 to improve water for agricultural uses in the southern Delta. Late in the summer of 1977, a rock barrier was constructed in Dutch Slough to increase the flow of fresh water into the southern portion of the western Delta.

During the late summer of 1976, a barrier was constructed in Sutter Slough to increase the amount of water transferred across the Delta. This barrier was effective for approximately two months and it was then breached. During 1977, there was so little flow in the Sacramento River that this barrier was not installed.

Efforts were made to offset the severe shortage of water in some areas by a number of water exchanges and transfers. SWP contractors in Southern California were able to find other sources of water and to thus relinquish their water for use in areas of greater need. Principally this involved greater use of Colorado River water. Coachella Valley County Water District and Desert Water Agency gave up all their scheduled deliveries, and the Metropolitan Water District of Southern California (MWD) and the San Bernardino Valley Municipal Water District were able to forego a portion of their deliveries. The water these agencies made available was used by agriculture, mainly in the San Joaquin Valley. Because of this exchange, San Joaquin Valley water contractors will receive the equivalent of 91 percent of their 1977 entitlement. Without it, they would have received 40 percent.

One urban area to benefit from the water exchange was the Marin Municipal Water District, which will receive approximately 13 cubic hectometres (10,800 acre-feet) of water. A portion of this water was provided by the State Water Project's South Bay Aqueduct in a complicated exchange involving the City of San Francisco, City of Hayward, and East Bay Municipal Utility District. Since mid-September, the water for Marin County has been taken directly into East Bay's Middle River pumping plant. The water crosses San Francisco Bay in a temporary pipeline on the Richmond-San Rafael Bridge.

The City of San Francisco has contracted with the State Water Project for delivery of 12 cubic hectometres (10,000 acre-feet) of the Southern California exchange water. This delivery is being made from the South Bay Aqueduct into the San Antonio Reservoir and commenced in mid-September 1977.



Pumping plant installed in Middle River by East Bay Municipal Utility District and DWR to provide better quality water for Contra Costa Water District. This facility started operating in June 1977.

In another move to make more effective use of water, several San Joaquin Valley agricultural water contractors proposed pumping ground water into the California Aqueduct when they were unable to fully use the water their wells produced. Although, in most cases, the ground water was of such poor quality that it would have downgraded the water for all downstream water users, a few contractors were able to blend the relatively poor ground water with SWP water at points outside the aqueduct, thereby increasing the quantity of agricultural water without making it unusable.

Fish and wildlife were also severely affected by the very dry conditions that occurred in 1977. Some of the smaller streams dried up completely, killing fish and reducing wildlife watering holes. Even larger streams were very low and unusually warm. To assist the Department of Fish and Game in maintaining a fall salmon spawning run, the State Water Project released cool water from the lower levels of Lake Oroville to the Feather River Fish Hatchery. DFG is also using the hatchery to rear salmon from the Sacramento River and steelhead trout from the American River.

Lessons of a Record-Setting Dry Period

The summer of 1976 was indeed a trying period, but it also was a valuable learning experience. Some of the most important lessons related to the ability of the Department of Water Resources to reasonably anticipate or react to various new conditions arising from the drought. Knowledge gained during the year demonstrated that, because such physical factors as barometric pressure, wind direction, and tidal fluctuation can alter conditions in the Delta so rapidly, they present problems that are almost impossible to cope with on a day-to-day basis.

Even though 1976 had been a dry year with its resulting problems, 1977 proved to be substantially worse. Full entitlement quantities of water could not be delivered to the State Water Project contractors; Delta water quality could not be maintained to previous standards; and project reservoirs were drawn down to much lower levels. Alternative water supplies had to be provided for portions of the State that had never before experienced severe water shortages.

The most important aspect of the drought was the fact that in an emergency, federal, State and local water agencies can and will work together to minimize its effects. This is shown by the many water exchanges and mutual use of existing and new facilities that occurred, and the Water Resources Control Board's response to Delta problems in modifying its standards. Actions in 1976 and 1977 have shown that, when the crunch is on, local agencies are willing to use their systems to serve other water districts.

A history of many years of plentiful water left the State Water Project less well prepared for a drought than it might have been. The lessons learned in these two years are being used to draw up new operating procedures for coping with the full probable range of water availability.

Levels in State Water Project reservoirs were very low by September 1977, the end of the 1976-77 water year. At the end of December 1977, the reservoirs were storing only 1 800 cubic hectometres (1,460,000 acre-feet) of water. Of this total, about 1 100 cubic hectometres (900,000 acre-feet) were held in Lake Oroville. The rest was stored in reservoirs south of the Delta. [Total project storage capacity is 7 168 cubic hectometres (5,811,000 acre-feet); Lake Oroville can store 4 364 cubic hectometres (3,538,000 acre-feet)].

If the 1977-78 water year (October-September) is as dry as 1976-77 has been, the State Water Project will probably deliver only about 801 cubic hectometres (650,000 acre-feet) of water. That is slightly more than half the amount delivered in 1976-77. Under this plan, the SWP, along with the CVP, will meet Sacramento basin uses (with current cutbacks), supply a Delta

Completed barrier across Dutch Slough.

outflow sufficient to meet existing Water Resources Control Board emergency regulations, and allow for a minimum level of diversions from the Delta. Municipal and industrial users will receive about half the project water their entitlements state, and very little project water will be available for agriculture.

However, if the situation should improve, deliveries will be increased and water quality in the Delta will improve. If, for example, California gets enough precipitation this winter to produce runoff equalling the runoff for three out of four years of recorded weather, the State Water Project could deliver all the entitlement water for which agencies have contracted and could partially refill its reservoirs. The likelihood of this occurring is encouraging because there is a 99 percent chance that 1977-78 will be wetter than 1976-77.

Information for this article was contributed by Donald H. McKillop, Chief, Water Operations Branch, and Clayton H. Magonigal, Chief, Water Measurement and Control Section, Sacramento.

The continuing history of the State Water Project and its construction, utility management, operations, and financing are reported each year by DWR in the Bulletin No. 132 series. The most recent issue is Bulletin No. 132-76, "The California State Water Project — 1976 Activities and Future Management Plans" (November 1977), which covers the project in 1976. A $5.00 charge is made for this publication.

Rock barrier on Old River, 1977.

The Suisun Marsh...

Its Future Depends on the Right Kind of Water

In earlier days in California, "suisun" (soo-soon) was the word the Indians used for "west wind." It meant the cool, moist breeze that blows steadily most of the year through the Carquinez Strait, across the Suisun Marsh, and into the Sacramento-San Joaquin Delta. To many Californians today, suisun is the word for ducks, thousands upon thousands of whom use the Suisun Marsh every year as a resting area as they travel along the Pacific Flyway. The marsh's wetlands serve as a temporary residence for many species of ducks, including pintails, American widgeons, shovelers, mallards, and canvasbacks. Other waterfowl are geese, coots, egrets, heron, and swans. All these are attracted by the plentiful supplies of food and water the marsh offers.

This year the marsh has some new residents — a tiny herd of tule elk that were introduced to Grizzly Island by the State Department of Fish and Game. These adaptable animals, which are reproducing well in Owens Valley and in Merced, Kern, and Lake Counties, are encountering feeding and other problems. For that reason, Fish and Game selected a group of eight and moved them to the marsh last spring on a trial basis. The herd was penned for a few weeks to acclimate it to its new environment, but it has been roaming freely since then, chiefly on the higher part of the island. The experiment seems to be succeeding so far. The herd now numbers 10 to 11 elk.

The marsh is situated in Solano County, south of the town of Fairfield. It is made up of 22 000 hectares (55,000 acres) of permanent marshlands, seasonal marshes, fallow uplands, grain fields, heavily vegetated levees, mud flats, and shallow bays. Over 4 000 hectares (10,000 acres) form Grizzly Island and Joice Island waterfowl management areas, which are owned by the State of California. The remaining 18 000 hectares (45,000 acres) are privately owned and support more than 150 private gun clubs.

[illegible] is a brackish area where fresh river flows and salty ocean currents mingle to form a unique and highly productive wildlife habitat. To fully preserve its value as a wildlife feeding area, the marsh must remain brackish. Careful maintenance of the right balance between salt water and fresh water is vital to its continued success. For one thing, the amount of salt in the soil greatly affects the growth of the alkali bulrush, a plant that is a big producer of seeds most ducks feed on. Alkali bulrush grows only in brackish water. When the soil is too saline, salt marsh vegetation takes over. When it is too "sweet," freshwater weeds flourish instead. In either case, the alkali bulrush is crowded out and its seed production is lowered.

Each October much of the marsh is flooded for duck hunting, the major activity from mid-October to mid-January. During February, March, and April, the duck ponds are alternately flooded and drained to leach ac-

cumulated salts from the soil, thus ensuring production of the most desirable duck forage. This area is drained during May and left dry until the following October to prevent mosquitoes from breeding, to discourage the growth of tules and cattails, and to allow for the necessary maintenance of the water control facilities. This cycle of operation depends on water of suitable quality, at least during leaching.

Amounts of fresh water available to balance the marsh depend on how much precipitation falls and how much water is used upstream in the Sacramento and San Joaquin River basins. The annual flow from these areas has varied widely from wet to dry years. In years of normal rainfall, before large water development projects modified streamflow in the Central Valley, the Sacramento and San Joaquin Rivers carried huge amounts of storm runoff for two or three months of the year. These great flows of fresh water poured through the Delta and into Suisun Bay, preventing sea water from entering marsh channels. However, during the balance of the year, especially in the summer, river flows dwindled greatly, and sea water was able to infiltrate the marsh.

In the 1850s, about the time efforts to reclaim the marsh were beginning, significant development of water for agricultural and municipal use was occurring in the Central Valley. Construction of dams was under way by 1870 and continued at an accelerated rate over the years, peaking between 1940 and 1970. At the outset, these developments did not substantially alter the natural runoff pattern into Suisun Bay. By 1930, however, dams, reservoirs, and other facilities were storing and diverting 12 300 cubic hectometres (10 million acre-feet) of water. The valley today has a potential storage capacity three times greater than that. Present and currently proposed federal and State water projects together will hold about 24 700 cubic hectometres (20 million acre-feet) and private water storage facilities probably exceed 12 300 cubic hectometres (10 million acre-feet). Storage alone is not the problem, though. Dams, canals, and other structures that facilitate the use of water in the valley and divert water to other basins have already lowered yearly Delta outflow from about 37 000 to 21 000 cubic hectometres (from nearly 30 to 17 million acre-feet). By 2000, this flow will be further lowered to about 11 600 cubic hectometres (9.4 million acre-feet).

Irrigation water that drains from valley agricultural lands into the Delta is another aspect of the problem. This water is high in salts and increases salinity in the Delta and ultimately in Suisun Bay.

The State Water Resources Control Board entered the marsh picture in 1978 when it issued its Delta water rights Decision 1485, following lengthy hearings in 1976 and 1978. In D-1485, the Board established specific water quality standards designed to

protect the waterfowl habitat of the marsh. Stated briefly, they provide that the salinity of the first foot of soil cannot exceed 9,000 parts per million of total dissolved solids (mostly salts) between April 15 and June 1. During this period, low concentrations of salt are essential for the continued growth of alkali bulrush and other important marsh plants.

At present, the repeated leaching of the soil to control salt is achieved by a tidal pumping process. Inlet and outlet structures built into the levees provide one-way flow in and out of ponds. At high tide, the water enters through one opening and, at low tide, it flows out through another. Whenever possible, these structures are placed on opposite sides of a pond to give maximum circulation.

Water of the proper quality can be provided to the marsh in several ways. One is to send water directly to each island or pond. This is a very expensive procedure and one that carries with it the danger of introducing an undesirably large amount of fresh water. Another way is to dilute channel salinities by introducing high-quality water at the upstream ends of the channels. This procedure runs the risk of creating a fresh-water marsh at the upstream ends, a brackish water marsh in the middle, and a salt-water marsh near the bay.

Possibilities for delivering the type of water that is best for the marsh are presently being investigated by the Four-Agency Technical Committee, made up of representatives of two State agencies, the Departments of Water Resources and Fish and Game, and two federal agencies, the Bureau of Reclamation and the Fish and Wildlife Service. The Four-Agency Suisun Marsh Management Study is evaluating a water supply and management plan to protect and enhance the waterfowl habitat. As part of this work, the Bureau has developed a wastewater demonstration plot near Cordelia to determine the practicability of using treated water along with various marsh management techniques.

Historic records of channel salinities tend to indicate that the marsh can survive a dry period without sustaining irreparable damage. When soil salinity exceeds the optimum level for several years, some vegetation is lost, but the loss is not permanent. When conditions improve, the plants grow back. Current studies indicate that, were it not for the present drought, water in the marsh would be of adequate quality, although it would be present for a shorter time and leaching would have to be speeded up. Now that we are in a critical water period, the marsh's ability to withstand adverse conditions is being severely tested.

The Department of Fish and Game reports that difficulties are being encountered. Populations of young American shad are down significantly. A rise in the salt content of the water is expected to cut seed production by some vegetation perhaps as much as 70 percent.

To offset the saltier water entering the marsh because of drought conditions, in April 1977 a supply of fresher water was brought from Montezuma Slough through Grizzly and Roaring River Sloughs to the area of Wheeler and Simmons Islands. Delivery of this water, which was timed to improve seed germination of marsh plants in May and June, was financed jointly by the Departments of Water Resources and Fish and Game and the owners of nine duck clubs in this area. Although the project was temporary, it demonstrated the usefulness of a permanent overland water supply for the region, a possibility that is being studied at present by the Four-Agency Committee.

The Department of Water Resources (DWR) and the State Water Resources Control Board have together drafted legislation that would, if enacted, affect conditions in the marsh far into the future. Under this legislation, which also involves the Delta and the operation of the State Water Project and the Central Valley Project (CVP), the Bureau of Reclamation and DWR would preserve fish and wildlife in the marsh at their present level and ultimately raise conditions for them to the best possible level. The Bureau would provide CVP water to accomplish this work. The owners of marsh lands would agree to permanently manage their acreages in ways that would assure an adequate wildlife habitat. Costs of this long-range improvement would be shared by both private and public interests.

Recent legislation enacted by the State Legislature will affect the future of the marsh. Assembly Bill 1717, passed in 1977, defines more precisely the marsh's boundaries and establishes a land use control plan for the area. The purpose of this bill is to ensure that the marsh is maintained and developed in ways that are beneficial to wildlife that inhabit it.

Change takes place slowly in the marsh. The drought's influence on conditions there will occur gradually over a long period, allowing time for management efforts such as last April's project to take effect. Ensuring good quality water supplies during the leaching cycles is a critical factor. The Suisun Marsh will come through this difficult dry period successfully if federal, State, and local government agencies and private landowners continue to work together to preserve it.

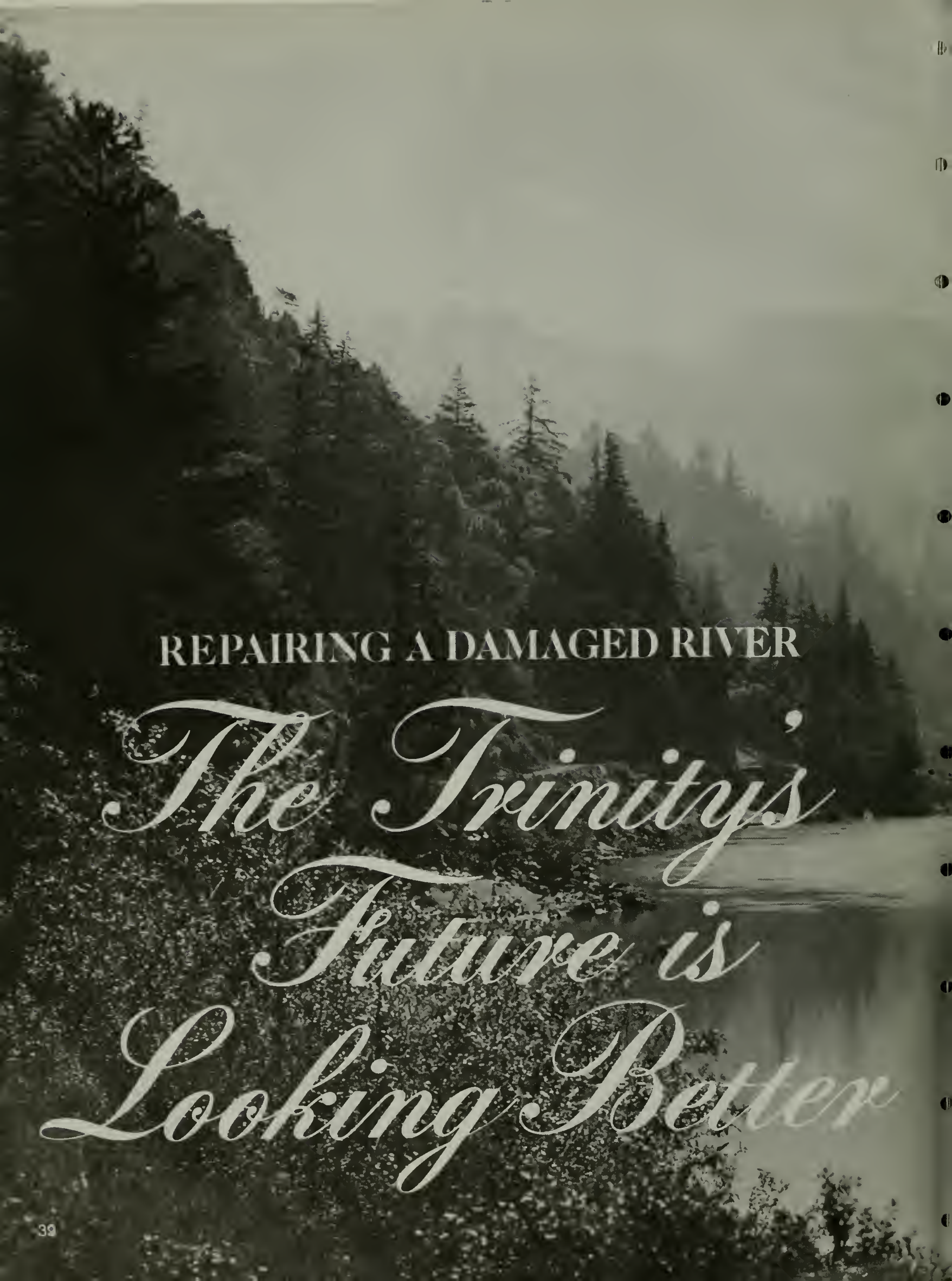
Information for this article was contributed by Mathias V. Hilling, Water Resources Engineering Associate; and George Deatherage, Chief, Water Contracts Management; both of the Central District Office, Sacramento.

Fishing on Joice Island

Egrets on Joice Island

Geese on Grizzly Island

White-tailed kite in the marsh



REPAIRING A DAMAGED RIVER

The Trinity's Future is Looking Better

Flashing and sparkling through the lofty mountains of Trinity County and the wild Coast Range of Humboldt County, the Trinity River historically has been one of California's finest for fishing and retreating from the concerns of the present. The solitary angler, seeking steelhead, the seagoing fisherman working offshore for Trinity-spawned king salmon — both share the bounty the river has provided since beyond memory, when Indians were the only humans to leave their imprint along its shores and feed on its rich harvest.

No more. Modern-day activities along the river's course have all but extinguished the fabled fisheries of the Trinity. From the late 1800s until 1950, the frenzy for gold, with typical disregard for its setting, laid waste to the ore producing areas of the basin and filled the river with debris. Earth from hydraulic mining, where immense water cannons literally blasted away the soft earth to wash out the flakes of gold that it contained, are still present in barren and ugly heaps along parts of the stream.

Even before miners had decamped, the loggers moved in. It was the 1940s and the need for vital building materials left little time for such gentle concern as regard for the landscape. The hills above the Trinity were logged bare. Roads were bulldozed through the forest with scarce consideration for erosion; scars were carved in the hillside where logs were dragged up to waiting trucks, becoming torrents of mud in the rain as logging road and embankment dissolved and flowed down to the river.

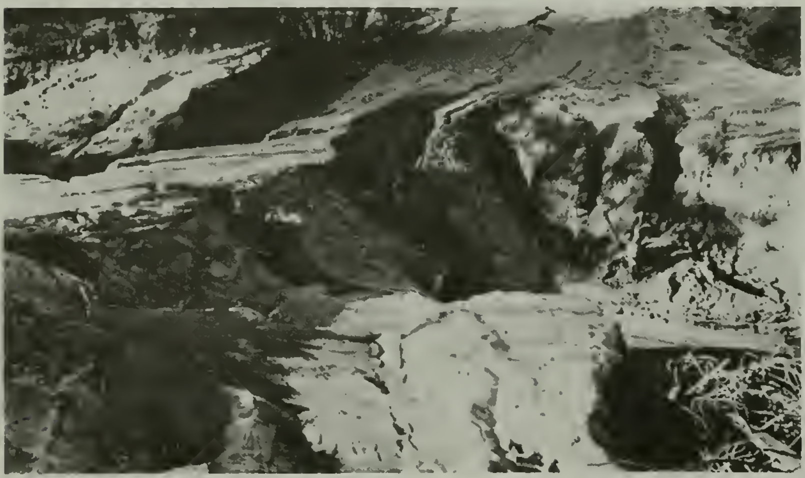
Through all this, the river and its inhabitants endured, and the fall season still witnessed spectacular runs of anadromous (from the Greek, meaning "running uphill") or migrating fish. It was the river's changeable temperament which saved it. Quiet one day, it could become a torrent the next, when a summer thundershower or sudden snowmelt from unseasonably warm winter weather occurred and swept away the accumulated silt caused by human activities, cleansing the spawning riffles that salmon need to deposit their eggs, and sweeping out the deep pools they use for resting places in their arduous journeys to and from the sea.

The abuses of the miners and the loggers abated. Most of the scars they left were beginning to disappear, and fish still fought their way up the lovely cataracts of the Trinity each year to spawn a new generation. Then, in the early 1960s, two dams rose on the Trinity River that were to have a telling influence. The larger of those structures, Trinity Dam, creates a big reservoir called Clair Engle Lake, whose waters drop to the hydroelectric turbines at the dam's base. A short distance downstream, the river is stopped again by Lewiston Diversion Dam, and much of the water is diverted through a tunnel in the mountains to the Sacramento River. Fish native to the upper reaches of the Trinity River find their way blocked by the wall of earth and rock that forms the dam. And, to an increasing extent, they could not find the spawning riffles below it either, because the often-hurrying waters which had cleared them and replenished their gravels were slow and steady now and readily dropped their bedloads of silt instead of sweeping it to sea. The resting pools filled and gave no sanctuary for the fish to hide in and rest during their migrations. The yearly runs dwindled. Anglers went away disappointed. Commercial deep-sea fisheries took smaller catches. People whose lives were reduced by the decline of the river were resentful, and their anger simmered for a long time.

It wasn't only the fault of the dams. A hatchery had been built at Lewiston to provide artificial spawning and nursery habitat for the displaced upstream fish. The young were coddled and nurtured from the egg to the "smolt", the juvenile fish which is ready for release to the sea. When it was determined that the hatchery waters were too cold for the needed development, a device was built to warm them. But still, few returned to spawn again, and the exact reasons are not yet known. It may be they become diseased when they reach the Klamath River. Biologists are testing this now. Though less spectacularly than in the Trinity, fish populations in many North Coast streams were declining.

Nor did the dams, Trinity and Lewiston, cause the sedimentation. They prevented the natural flushing action that kept the fish habitat clear. This was a highly visible change and an easy target for resentment and oversimplification of more complex problems.

But, by 1971, it was sadly apparent that the Trinity River needed help if its fishery were to survive. Its fast flows were trapped behind Trinity Dam, and its fish population gravely reduced. The eroded soil that washed into it was covering the best spawning places and filling the best fishing holes. It was a clean sand, mostly decomposed granite rock and mostly from a single source — a much-abused tributary stream



EROSION – *This access road, originally built by loggers and now restored each year by a private landowner, becomes a watercourse each rainy season and washes into Grass Valley Creek, the Trinity's main source of silt.*

HYDRAULIC MINING – *In this picture, taken in 1950 in Trinity County, the enormous size and destructive power of the water hoses, called monitors, can be seen. The natural terrain has been cut to steep bluffs and washed away. The operators, scarcely visible, are dwarfed by the great jets of water.*

King salmon making a hard climb at Burnt Ranch Falls. Too often now the quiet pools where fish could once rest after their exertions are filled with sand.

below Lewiston called Grass Valley Creek. State and federal agencies began to discuss ways to halt the sedimentation and restore the fish habitat. But no funding for specific projects was forthcoming in 1971, and the decline continued.

In 1974, the Department of Water Resources obtained $125,000 to begin studying the problems and possible solutions for the Trinity. Twenty-five thousand dollars ($25,000) of this was turned over to a companion agency, the Department of Fish and Game, which matched the sum and began preliminary work on fish migration in the river. The Department of Water Resources' North Coast fisheries enhancement program was shifted to focus solely on the Trinity, and the federal agency concerned, the Bureau of Reclamation, followed suit with its own North Coast program. The combined task force, established three years earlier, took on new life and began enlarging its membership. Ultimately it included, on the federal side, the Bureaus of Indian Affairs, Reclamation, and Land Management, the U.S. Forest Service, and the Fish and Wildlife and Soil Conservation Services. California was represented by its departments of Water Resources and Fish and Game. Local governments, the Trinity and Humboldt County boards of supervisors, and the Hoopa Valley Indian Tribe, through whose lands the Trinity flows, all became active participants in the Trinity River Task Force. Acting as a body, they have ordered and coordinated efforts to heal the river since 1974. With energetic representation by Congressman Harold Johnson, funding increased each year, from $.5 million in 1976 to $1.5 million for 1977, and $2.0 million for this year. Much of the impetus for this was provided by local residents, who campaigned for the river in many ways, including sending a high school delegation — an environment class — to Washington to request assistance.

The entire Trinity River Basin, forests and spoiled areas, land animals and fish, riverflow-rates and water temperatures, fish movements and mortality — all come under tightening scrutiny in the hope that

JET-PUMP DREDGE – *This method of clearing sand from pools in the Trinity was conceived by the Department of Water Resources to do the job without muddying the waters. The barge with the pump can be moved in a 100-metre stretch of the river at a time. It sucks sand from the bottom, without sending clouds of it downstream, and discharges it to the settling pool in the background for removal by earthmoving equipment.*

MARKING FISH – *Before the young fish are released, biologists mark them to get a count of the numbers returning to the hatchery the following year. Far too few have made it.*

GRASS VALLEY CREEK – *Heavily silted-in and cluttered with old logging debris, the creek flows into the Trinity, producing most of the sand which wrecks the river's fish habitat.*

WATER SKIMMER – *Designed by the Department of Water Resources, this device skims the warmer surface water behind Lewiston Dam and sends it through the gates to the fish hatchery below. The gates or penstocks of the dam are set well below the normal surface of the lake where the water remains too cold for the young fish to grow to the proper size for release downstream to the sea.*

what people have taken away, people can replace.

Among many jobs assigned to the Department of Water Resources by the Task Force were the problems of learning how to stop the sedimentation and to remove what had already occurred.

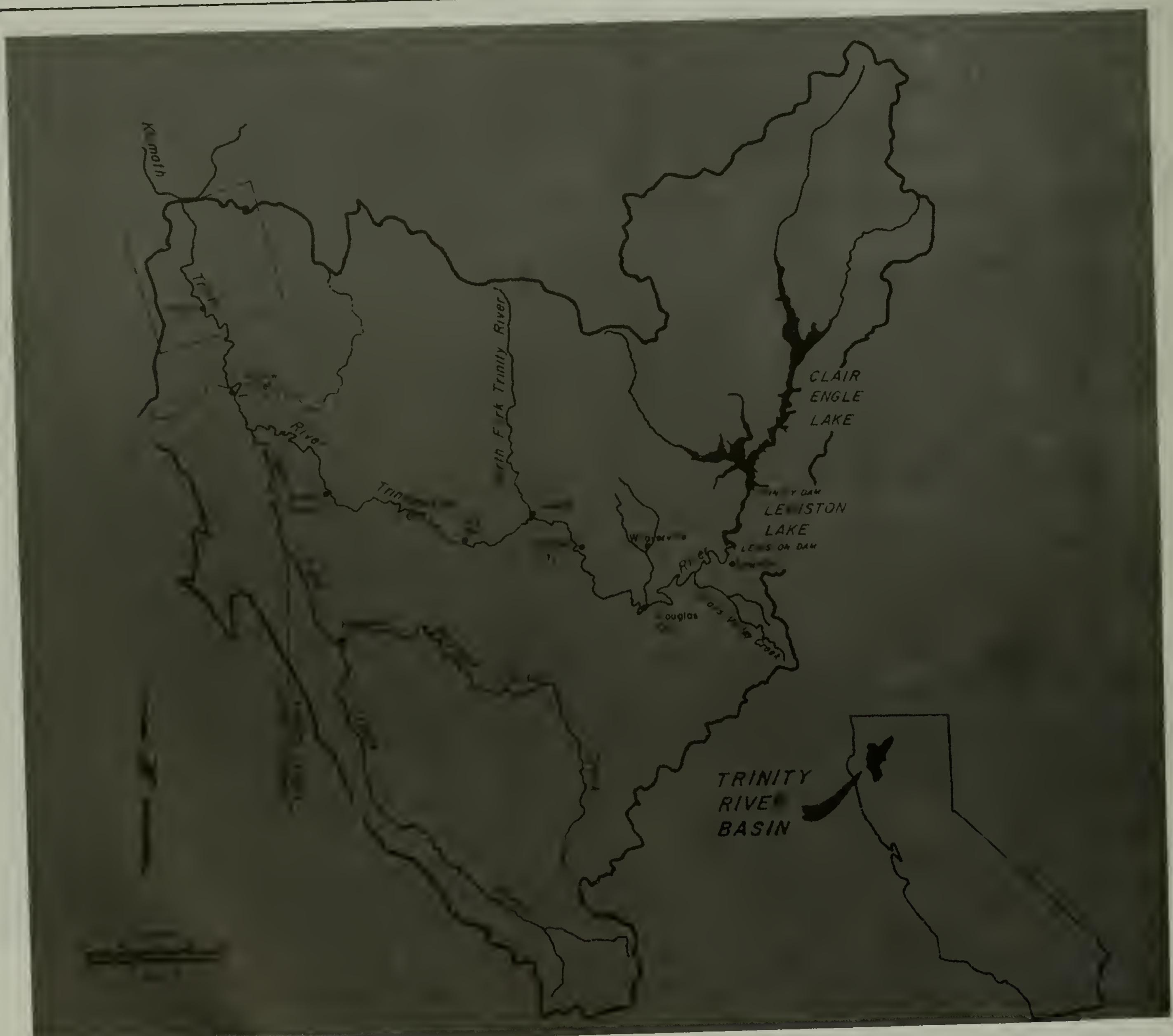
In spring 1977, a quiet spot on the Trinity River called Poker Bar was wakened by the sound of diesel engines, as Department personnel began removing decomposed granite sand from a shallow bend of the creek which had once housed a fine old fishing hole, said to have been more than 7½ metres (25 feet) deep. The residents of the small settlement there watched with interest as previously untried concepts were tested in the river. The objectives of the operation were twofold: to clear the pool and, in doing so, to provide a natural settling basin for sand, which could then easily be evacuated.

The heart of the project was a suction device called a jet-pump which floated on a tiny barge, sucked the sand from the river bottom, and spewed it out on shore. Earthmoving equipment stood by to transport the sand to a permanent disposal site, where it was used to cover sterile and unsightly piles of old dredger tailings.

By much trial and error, the system was made to work, and some 2 675 cubic metres (3,500 cubic yards) of sediment were hauled from the pool at Poker Bar in a month's time. Fish hid in it again, and sportsmen came to find them.

While this was under way, other teams from the Department were reconnoitering the Grass Valley Creek drainage area to seek ways to halt the flow of sediment into the Trinity and to study the environmental impact of the alternatives considered. The aim was to halt the sediment — if possible, without halting fish movement — while creating as little adverse effect as possible.

Seven alternatives were selected for close study. An archaeological survey was conducted to search for cultural artifacts from



Flowing for most of its length through Trinity County, the river ultimately joins the Klamath River and reaches the sea at the northwestern corner of the State.

Indian inhabitants and early white settlement. Fish and wildlife specialists studied the various sites to determine impact. As work progressed, residents of the affected area were consulted to see which they preferred.

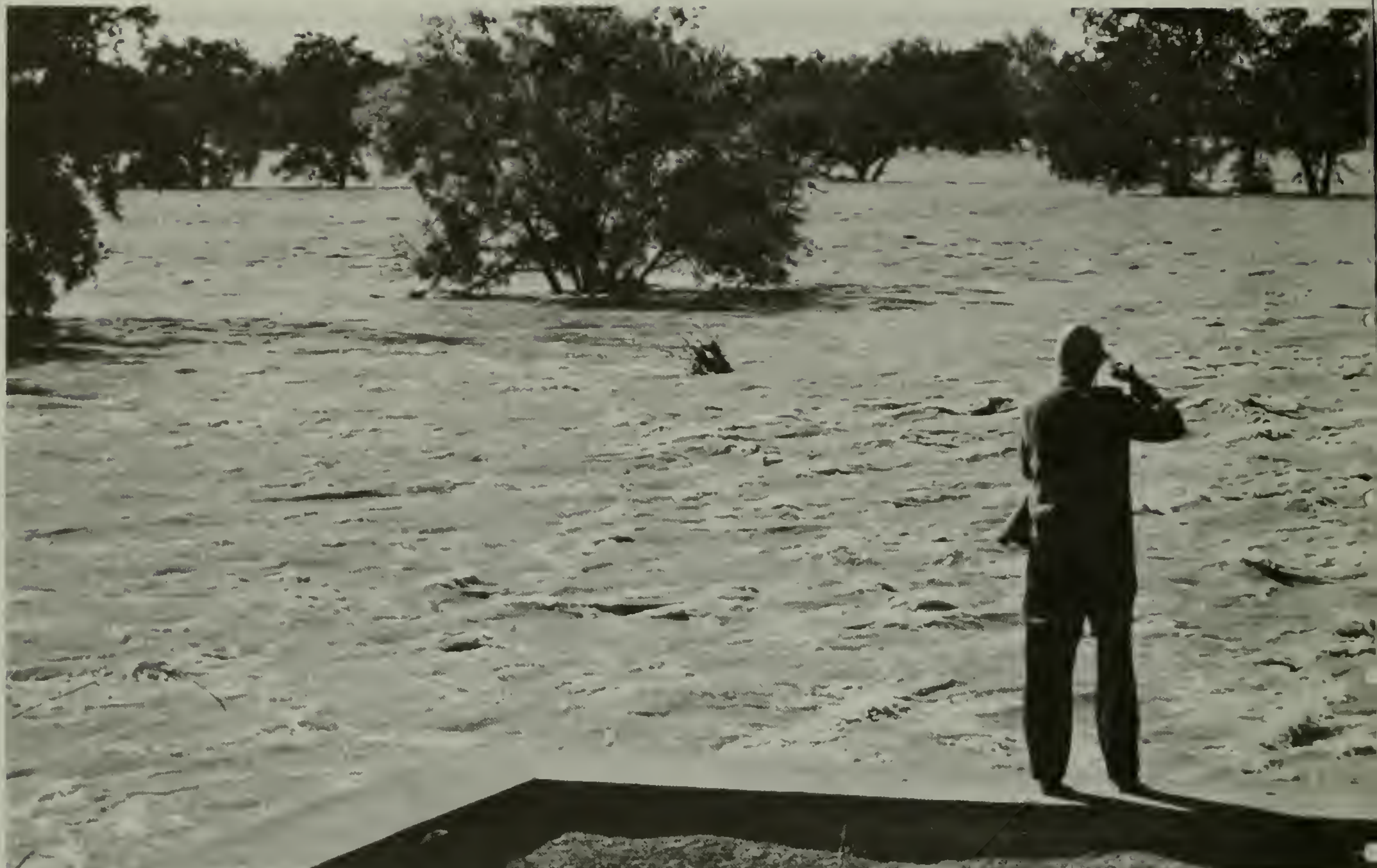
One project received virtually unanimous support from the Trinity County officials and local residents, and, ultimately, the Department's recommendation. This was a plan for a dam, 24 metres (80 feet) high and 16 kilometres (10 miles) from the point where Grass Valley Creek enters the Trinity. The dam would block a quarter of the creek's drainage area, about 23 square kilometres (9 square miles) and would catch and store two-thirds of its sediment flow. Nineteen-seventy-nine is the year that should see the construction of this project and, along with other efforts under way by the Department and members of the Task Force, should halt the encroachment of sand into the fish habitat of the river.

A return to near-natural flow conditions should ensure the cleansing of spawning gravels of whatever sediments are now halted by debris-trapping structures or are dredged away. When the drought eases sufficiently, greater releases from Shasta Dam will be tried to see whether spawning is enhanced.

Meanwhile, biologists continue to search for the other causes of the declining fish populations which are not attributable to dams and sediments. Many factors contributing to the disappearance of anadromous fish in the Trinity have been identified. Some may never be known. But intensive study, experimentation, and restoration of conditions favorable to steelhead and salmon may well bring them home again without ever solving all the riddles.

This article was contributed by Mitchell Clogg, Research Writer, Northern District Office, Red Bluff.

TRINITY DAM – *As it appeared while under construction in 1961. Clair Engle Lake, behind the dam, is a recreation spot for some 500,000 visitors each year.*



Dry Year or Wet Year... Flood Management Planning Must Continue

A dictionary definition of a flood describes it as water flowing over land that is normally dry. While this is essentially correct, it falls far short of the entire situation because it fails to take into account our real concern with flooding — the human suffering, the deaths, and the property damage wrought when rivers run wild. We can measure the effects of flooding by the enormous dollar losses in homes and crops destroyed — an amount that rises nationally year by year — but no price tag is possible for the injuries, disruption of lives, and loss of life that occurs.

Now that California is in the grip of a record-breaking dry period, a natural question to ask is: What is the point in worrying about flood management? The fact is, no matter the weather, or even the season of the year, many parts of California must stand ready for the possibility of flooding. Even in 1976, the third driest year of the century, several millions of dollars in flood damage were caused by thunderstorms and heavy rain in some desert regions of Southern California. In actuality, mounting the most effective defenses against floods in flood-prone regions can require a very long time, often as much as several years. The answer, then, is: Flood management must remain a year-round process, wet year or dry.

Flood management is the attempt to re-

The Sacramento River at Fremont Weir shows how the valley floor might look if flood water were not held in check by levees and bypass

duce or eliminate flood damage. The traditional approach has been to cut floods down in size by building engineering works, dams, levees, and channels. The idea behind this type of effort is that the smaller the flood, the lighter the damage. Two other ways of alleviating flood damage have been devised: warning systems and tax benefits.

Predicting the height and arrival of a flood crest does not lower the level in the river, of course, but flood warnings given in time permit residents to place sand bags around their property and take other actions to reduce damage, or, if the danger is extreme, to leave their homes and go to a place of safety. (The Department of Water Resources and the National Weather Service together operate a flood warning center in Sacramento, which uses telemetered precipitation and river stage data, computers, and mathematical techniques to predict flood stages on major Northern California streams, and warns of impending flood hazards when rivers are high.)

Tax adjustments for land restricted to agricultural, recreational, conservation, or other open-space uses could prevent unwise development of low-lying lands. Such incentives can reduce flood damage and preserve agricultural land.

An Alternate Answer

Within the last 40 years or so, we have come to realize that we have still another course we can follow. We can see to it that people and damageable property are elsewhere when a flood arrives. In other words, losses can be reduced by discouraging development of lands vulnerable to floods and, in so doing, discourage people from settling there. If, in time, it becomes possible to restrict the use of flood-prone lands, these areas can be used to channel flood water off safely without endangering life or destroying property. This type of management is called flood plain management, or, sometimes, nonstructural flood control. Flood plain management has two objectives: to direct people to safer locations and to stem as much as possible the rising costs of repairing flood damage.

Interest in flood plain management as an alternative management method has been growing for a number of reasons. The costs of erecting large engineering structures have escalated enormously; we are now more interested generally in protecting the environment; and people have come to recognize that the capacity of control works can be exceeded. The reality is that a flood greater than one which a structure was designed to contain can occur at any time, even though it occurs infrequently. We can also question the financial efficiency of traditional flood control methods.

Sometimes it is actually beneficial to allow flood flows to race unimpeded to the sea. The force of this water clears the rivers of sand and other sediments that might otherwise choke them and so prevent them from carrying a normal flow. An example of excessive structural control is the Colorado River, parts of which were once navigable by steamboats. These can now be waded during most of the year. Floods also carry heavy loads of sand and sediments to the ocean beaches and replenish beach sands that are constantly being removed by waves. Dams sometimes interfere with this necessary natural process.

Natural disasters have been the concern of government since the earliest periods of history. In the United States, we tend to think of flood disaster control in terms of the massive multipurpose dams and reservoirs constructed by the federal government. These works are certainly spectacular; however, other levels of government have also built many flood control facilities, ranging from the simplest drainage channels to Oroville Dam, built by the State of California.

The construction of large-scale flood control works by the federal government began in the depression years of the 1930s. Since then, federal taxpayers have invested over $10 billion in these works. If this investment was financially efficient, we should have seen a reduction in the annual amount of flood losses. Quite the reverse is true. Our annual national losses from floods currently exceed $1 billion, and this figure is rising rapidly year by year. The U.S. Water Resources Council estimates that more than $5 billion will be spent annually by 2020, unless we find a better way to manage our flood plains. Even worse to contemplate is the human suffering that accompanies losses of that size. Clearly, the construction of bigger dams and more extensive levee systems has not been the complete answer. Something else is needed.

The Earliest Efforts

In 1966, a task force made up of federal, State, and local government experts, plus some from the private sector, produced, at the President's request, a report titled, "A Unified National Program for Managing Flood Losses." When transmitted to Congress, this report became known as House Document No. 465. It urged Congress and the Executive Branch to provide several flood management tools. These included:

- A National Flood Insurance Program.
- An executive order requiring federal officials responsible for land use decisions to consider flood hazard in selecting or disposing of land.
- A program to provide flood plain managers with technical information.
- A national program for flood plain management.

Both Congress and the President acted to carry out these recommendations. The President signed Executive Order No. 11296, covering land use decisions, and, as part of the 1966 Flood Control Act, Congress authorized the Corps of Engineers to provide technical information and advice on flooding hazards. The National Flood Insurance Program was part of the 1968 Omnibus Housing Bill.

The Corps of Engineers' activity under this legislation has come to be known as its Flood Plain Management Services Program, which aids local governments by giving technical guidance and by making long-range plans to reduce flood damage. The most familiar product of the program is the flood plain information report, showing geographic areas that would be inundated by floods of various sizes. These reports have been prepared for more than 75 locations in California, and they have proven to be valuable tools for California's local flood management and planning officials. In several instances, they have been the basis for flood plain zoning. Demand for these services has exceeded the Corps' capacity to perform them; therefore, several other federal and some State agencies, including the Department of Water Resources, now offer a similar service. The Corps' services are provided at no cost to the community; the Department's services are provided on a cost-sharing basis.

Reducing the Risks

Probably the most promising flood plain management tool is the National Flood Insurance Program. This program recognizes that local governments are understandably reluctant to impose land use controls they feel might affect local businesses unfavorably. Some kind of incentive is often necessary to bring action.

Recognition of both the advantages and disadvantages of flood plain management led Congress in 1968 to devise the National Flood Insurance Program, which allowed a community to provide previously unavailable flood insurance to its property owners in return for the community's commitment to begin controlling the use of land in its flood-prone areas. The program was to be tailored to the amount of information the community received from the Federal Insurance Administration (FIA).

The program was generally accepted by local legislative bodies, but it was pretty much ignored by property owners, who failed to see it as an opportunity to purchase a previously unavailable type of protection. As an illustration, when hurricane Agnes struck the east coast in 1972, only two flood insurance policies were in force in the City of Wilkes-Barre, Pennsylvania — even though the insurance was available and the city was situated on a river with a long history of flooding.

Three billion dollars in property losses and the enormous toll in human losses caused by this hurricane proved to be the catalysts which prompted Congress to pass the Flood Disaster Protection Act of 1973. This act makes the Flood Insurance Program what it is today — an inducement for communities to adopt flood plain management.

Two of the most significant portions of this act require that the federal government's expenditures for development in a flood-prone community be protected. Potential buyers of land situated in areas officially identified as subject to flooding, whose loans were to be backed by the United States, had to buy flood insurance before they could obtain the loans. Such backing included mortgage loans from federally regulated or supervised lenders such as banks, credit unions, and savings and loan associations, as well as direct aid from the Veterans Administration and the Farmers Home Administration.

The impact of these requirements was demonstrated by the marked increase in the number of California communities participating in the program. Slightly more than 100 of the State's eligible jurisdictions were in the program when the act became effective. Today the number is 386. Only 20 communities with official flood-hazard areas have failed to join the effort. For the most part, the nonparticipants have either very small areas endangered by floods or areas which are developed as parks or croplands or for other uses not seriously damaged by flooding.

The Housing and Community Development Act of 1977 partially reversed the mandatory insurance requirements. Conventional loans may now be made on property in identified flood-prone areas of communities that are not participating in the flood insurance program.

Federal Flood Insurance Program

Section – Not to scale

Plan View – Not to scale

How the Program Works

Probably the best way to describe the program is to list the steps a community takes to participate in it.

First, the community receives a Federal Insurance Administration flood hazard boundary map showing the local area that would be inundated by a 100-year flood.* The map's accuracy can be challenged. Financial sanctions go into effect in one year.

Then, the community's legislative body asks to participate in the program. Its application is accompanied by evidence of a minimum flood plain management program, basically a building permit system and a commitment to begin a more complex and vigorous program when the FIA furnishes additional hydrologic data.

After the application is accepted, property owners can buy subsidized insurance at uniform rates. For a residence, $35,000 worth of structural coverage can be obtained at $0.25 per year per $100 worth of coverage. This is the so-called emergency phase of the program.

The FIA, in cooperation with the State, then arranges for a detailed hydrologic study. This study will do a number of things. It will refine and supplant the flood hazard boundary map, show elevations of the flood water surface for the 100-year flood, and, where appropriate, show the designated floodway. The FIA defines a designated floodway as ". . . the channel of a river or other water course and adjacent land areas that must be reserved in order to discharge the 100-year flood without cumulatively increasing the water surface elevation more than one foot at any one point," or in other words, a channel large enough to safely pass a very heavy flow.

After it has been reviewed by the community and the FIA, the study is officially presented to residents of the community, who may, if they wish, contest the flood elevations on technical grounds. When all review is completed and disputes resolved, the community has six months to develop a complete flood plain management program. The most significant aspect of this program is the requirement that the first habitable floor of all new construction must be at or above the surface of the 100-year flood. Where there is a designated floodway, the community must forbid virtually all new construction.

Although no California community is this far down the line now, many land use planners indicate they will probably propose a two-zone flood area — the designated floodway, where new construction is essentially forbidden, and a flood plain fringe, which allows development, provided buildings are elevated.

After the community has put its complete flood plain management program into action, property owners can purchase additional insurance — another $35,000 for a home — at actuarial rates. These rates vary with the structure's location, type, and elevation above or below the 100-year flood. To build in a flood-prone area, a developer must elevate the buildings or pay a high insurance premium. If they are not elevated, the builder must also obtain a variance from local building officials. However, this procedure can jeopardize the whole program. If the FIA regards a variance unfavorably, it can suspend the community from the program, thereby cutting off sources of money for loans.

It is too early to assess the long-range effects of the National Flood Insurance Program in California. However, it is a promising tool for planning the wise and economical use of our flood-prone lands. The future will tell us of the program's social, political, and economic impact.

The U.S. Water Resources Council recently published a report titled, "A Unified National Program for Flood Plain Management and Executive Order 11296 — Flood Hazard Evaluation Revised." This report sets forth a framework to guide the decision-making of officials at all levels of government. It presents strategies and tools to lessen flood losses, recommends actions to be taken by the several levels of government, and advocates preparing a handbook for local officials and striving for wider collection of flood damage statistics. It also updates the President's Executive Order No. 11296 regarding land use. The Department of Water Resources has written a Governor's Executive Order patterned after the revised presidential document. The State order agrees with recommended actions in the WRC report.

On May 24, 1977, the President signed an Executive Order ordering federal agencies responsible for buying, using, and selling federal lands to "evaluate the potential effects of any actions (they) may take in a floodplain" and to "consider alternatives to avoid adverse effects and incompatible development in the floodplains." One purpose of the directive was to keep from encouraging flood plain development when other courses of action were open.

Managing Floods in California

The State of California has two flood plain management programs. The Designated Floodway Program of the State Reclamation Board is applied only within the Central Valley. The Cobey-Alquist Flood Plain Management Program is applied statewide, wherever there is a federal flood control project.

The Reclamation Board's program began in 1969 and now covers over 900 miles of Central Valley streams. The program's aim is to preserve a stream channel's capacity to safely pass a 100-year flood. Floodway limits are delineated on maps. A permit from the Board is required for any encroachment within these lines. The Board attempts to persuade local governments to make the floodway part of an open-space element in a county's general plan for development.

The Cobey-Alquist program induces local government to adopt suitable flood plain regulations as a condition of receiving financial assistance from the State for purchasing the lands, easements, and rights of way required for a federal flood control project.

This act also gives the State's position on the regulation of flood plains in these words:

The term 100-year flood describes statistically an event that can be expected to occur once in 100 years over an extended period of time. It is not a measure of frequency but rather of odds. There is a 1-in-100, or 1 percent, chance that a 100-year flood will strike in any year. It can occur in two or more successive years or, more improbably, twice in a single year. It is even possible for 100 years to pass without a 100-year flood.

"It is the policy of this state to encourage local levels of government to plan land use regulations to accomplish flood plain management and to provide state assistance and guidance therefor as appropriate."

In developing a flood plain management program, local governments have a variety of options. Most often they enforce local land use restrictions, such as zoning laws, building codes, and subdivision regulations, all of which were first developed for reasons other than flood management. Most communities will use all these in developing a comprehensive plan. Zoning can exclude inappropriate use of a hazard area, while building codes can set minimum elevations above the 100-year flood level for new construction. Subdivision regulation assures adequate drainage and proper design of transportation facilities and utilities, as well as allowing officials to totally ban development in certain locations, such as an area where sewage cannot be adequately disposed of, or where the risk of flooding is extremely high.

Still another management technique is public ownership of the flood plain. Land held for this purpose can be used for parks, open space, or agriculture. A slight variation of this technique is the purchase of flooding rights. The Sacramento metropolitan area is protected by such a system. Privately-owned land in the Yolo Bypass is farmed, with the understanding that it will be inundated during periods of very high flow in the adjacent Sacramento River.

Problems with the Program

Use of these techniques is by no means easy or painless. Every approach has its opponents, many of whom are quite outspoken in expressing their opposition. Flood plain zoning is attacked by some as an uncompensated taking of land. A California court has issued a landmark decision covering a situation of this type. An owner of a mobile home park in Del Norte County was denied a permit to expand his facility on the grounds that the site was situated in a flood plain, a hazardous location. The owner alleged inverse condemnation; however, the appeal court held that the County's action was a legitimate exercise of its police power.

Developers and others with an economic interest in the use of land attack flood plain regulation on a number of counts. They contend that government has no right to dictate an owner's use of his real property. They state that identifying a particular area as a flood-hazard zone depresses its value. The argument against this is, of course, that the depressed value is the true and proper value. Opponents are frequently able to influence local legislative bodies, which are then unwilling to impose land controls. The possible financial sanctions of the Flood Insurance Program had, in the past, proven to be the most promising method of overcoming this reluctance. Recently, however, Congress relaxed these sanctions. A community may drop out of the program and abandon flood plain management without jeopardizing its development funding.

Several other problems are inherent in flood plain management programs. One of these is determining the potential magnitude of floods from which we seek to protect ourselves. Differing uses of land mean differing levels of safety. Clearly, a highly urbanized area needs a higher degree of protection than does farmland. The concept is easy to describe but extremely difficult to spell out specifically. The Flood Insurance Program has arbitrarily chosen the 100-year flood as the regulatory standard. While this is not correct for all land uses, it probably is a good average figure.

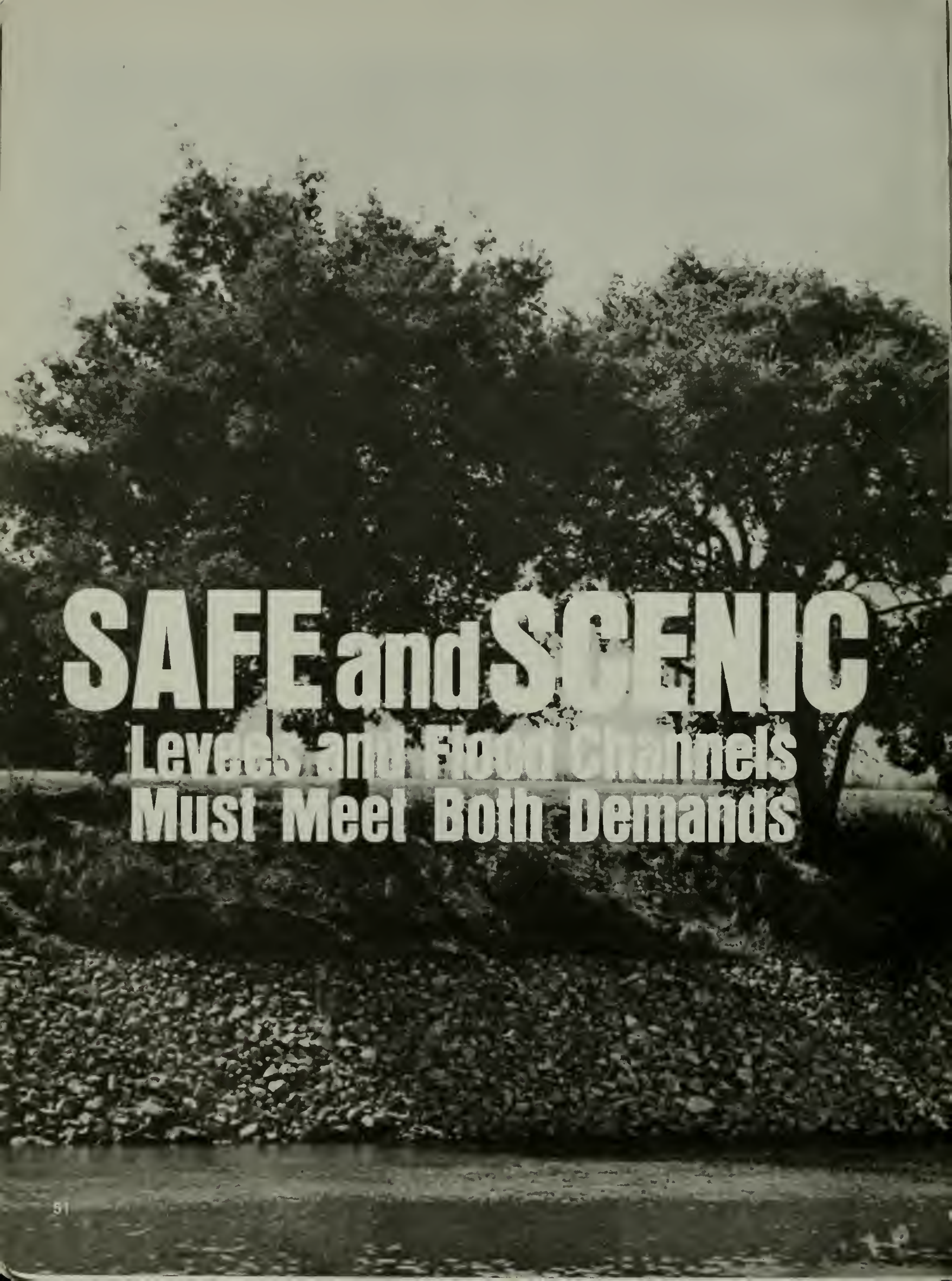
Coordinating the flood plain management programs of adjoining communities can be difficult and, as more and more communities develop the plans required by the insurance program, the difficulties will become more apparent. Because flooding does not respect political boundaries, the coordination effort will logically fall to State government. The Department of Water Resources anticipates expanded activity in this area.

Results of alternative flood management measures in already heavily-populated urban areas do not materialize as quickly or as visibly as they do when dams and levees are built. Almost irresistible political pressures often demand that such physical works be constructed. Flood plain management in urban areas offers long-term relief.

Success in applying the various alternatives outlined in this article will be long in coming. Each has social, political, and economic side-effects whose full impact will gradually be felt as local management programs are begun. Assessing the side-effects and the value of the alternatives will undoubtedly occupy flood management experts and lawmakers at all levels for years to come.

The potential for creating enormous and widespread havoc is amply demonstrated in this scene of high water on the Sacramento River in wetter years. The aerial view of the town of Rio Vista was taken in December 1964, when river flow reached about 14 200 cubic metres per second (500,000 cubic feet per second). Channel capacity at this location is about 16 900 cubic metres per second (600,000 cubic feet per second).

Information for this article was contributed by Jack G. Pardee, Chief, Flood Plain Management Branch, Sacramento.



SAFE and SCENIC

Levees and Flood Channels Must Meet Both Demands

The methods used to maintain flood channels and levee banks in California have come in for a good deal of public disapproval in recent years. Some of the adverse criticism arises from misunderstanding of the problems involved in this work, and some is due to the failure of agencies responsible for levee and channel maintenance to adequately consider the environment. In any event, the protests are usually triggered whenever esthetically pleasing natural vegetation is removed from a levee and replaced by a barren stretch of rock. The practices, the problems, and some solutions that are part of channel and levee maintenance are outlined here.

A big problem today in keeping flood control facilities in shape is trying to find a workable balance between efficient operation and environmental protection. Flood channels and levees exist first of all to contain flood flows and prevent the devastation that follows in their path. These structures must therefore be kept in condition to perform that job. At the same time, present-day demands to protect our natural environment require us to preserve the native plant life, wildlife habitats, scenic values, and recreational uses of a levee and channel system.

In 1850, when California became a State, much of the Central Valley was a vast marshland that was frequently inundated by winter floods when the Sacramento and San Joaquin Rivers spilled over their banks. With nothing standing in its way, the water spread widely across miles of land. Then, soon afterward, small sections of levees began to appear along the Sacramento River to protect early settlements. From these modest beginnings has evolved the Sacramento and San Joaquin Rivers Flood Control Projects, which oversees more than 2 560 kilometres (1,600 miles) of levees.

Large reservoirs such as Shasta Lake and Lake Oroville, with their great capacity to capture and temporarily hold upstream floodwater, have added significantly to the protection of valley lands lying outside the levees by delaying some storm runoff and reducing downstream peak flood levels. However, during larger storms, high river flows within downstream levees continue for many days. At these times, the levees are subject to the same heavy water pressure as earth dams. They must be carefully maintained to ensure that California's hundreds of miles of levees are safe enough to protect the lands behind them when the rivers rise. Their integrity is assured by the U.S. Corps of Engineers, which specifies the standards to be followed by the agency, either State or local, that looks after each federal flood control project. Some latitude is allowed, but major changes require approval of the Corps.

New Ideas

Past and present efforts to maintain flood control project channels and levees in a safe condition have sometimes had a detrimental effect on the environmental and esthetic aspects of these structures. The Department of Water Resources is working on ways to obtain a better balance of maintenance so that both flood control and environmental protection are properly achieved. Some of these have already been put into action.

DWR is negotiating with the Corps of Engineers for reappraisal of streams on which storage reservoirs have been built. The downstream flood protection these projects provide may enable the maintenance standards established by the Corps to be relaxed to allow more vegetation to grow on the levee slopes.

In addition to whatever modifications are considered sufficiently acceptable for immediate action, three other proposals for new maintenance methods are in the works. Some suggestions are: shaping levee slopes into terraces that will make preventive maintenance work easier; reshaping uneven terrain on landward levee slopes to allow mowing machines and other equipment to operate more effectively and to permit new vegetation to be planted; and subsidizing an irrigated revegetation program, subject to the Department's proposed water conserving landscape design standards and guidelines.

Several improvements have already been put into practice. Others can and will be carried out immediately. Still others need more study. This is an evolving process that requires constant effort to refine and adjust maintenance practices to meet environmental needs.

Each April, when the flood season has officially ended and the Department can assess its impacts and maintenance requirements, a work plan for the year ahead is drawn up for each DWR flood control maintenance yard. In the future, before the task is begun, DWR will look at what has been achieved to improve environmental practices and consider new ways of operating. In this way, maintenance can be continually adjusted to fit changing needs and resources. This new approach is clearly needed. The public's growing displeasure with denuded waterways and the steady disappearance of California's streambank habitat for wildlife demand that new methods be found.

Native trees on levees are being saved to preserve the natural beauty of many sites along the Sacramento River.

Maintenance Needs

Flood channel design capacities must be maintained, if streams are to safely pass flood flows at levels for which the levees and bypasses were constructed. This flow is often impeded by encroaching vegetative growth, debris, deposits of sediment, and buildings, fences, and orchards. Extensive removal of trees and brush has often been considered necessary — or expedient — to permit the required flow to pass without flood damage.

Flood control levees must remain stable so that they also contain the high flows for which they were built. The principal hazards to levee stability are erosion, burrowing animals (principally those that dig from the land side and burrow widely), large trees that may topple or cause an earth slide, and water moving through a portion of a levee weakened by prolonged water pressure, or water passing through an improperly sealed pipe that was abandoned when irrigation pumping ceased.

Good maintenance must not only anticipate these hazards but also allow access for crews to fight floods in the midst of major storms. In general, certain trees must be removed (and prohibited) when they endanger vulnerable levee slopes or stand in the way of inspection or flood fight activities; vegetation, debris, or other obstructions must be removed when they prevent control of burrowing rodents or when the flow capacity of the channel is being impaired. An all-weather roadway on the levee crown is essential to all levee maintenance.

A levee is also subjected to the erosive force of the water flowing at high velocity along its face and foundation. Many methods have been tried to modify this force. The most successful, from a purely engineering viewpoint, has been covering the slope with rock from the bottom to high water level. In the Sacramento and San Joaquin Rivers Flood Control Projects, some rock was placed at vulnerable areas when the levees were built, and substantial sections of riverbank and levee slope have been, and continue to be, protected with a blanket of rock after any major erosion is repaired.

Spraying rigs operating in tandem treat vegetation on levee.

Early-Day Methods

Channel and levee maintenance practices have evolved over the years in step with the development of modern equipment and sophisticated chemical herbicides and pesticides, and the continuing press of settlement of people along Central Valley waterways.

Before suitable mechanized equipment was available, channels and levees were cleared with hand labor. Many were entirely untouched and soon became tangled jungles of trees and brush. Crews of men armed with hoes, scythes, axes, and saws tried, and often failed, to make headway against rapidly growing cottonwoods, willows, weeds, and shrubs of all varieties. Fire turned out to be one of the most effective tools, up to a point. In those days, fires were set by torch and fought with wet barley sacks, and it was not uncommon for one to start burning out of control.

Early methods of erosion control involved the use of timber, old mattresses, wooden bulkheads, planting of bamboo and other vegetation, concrete paving, and grouted (cemented) rocks. The most successful has been uncemented rock that is large and heavy enough to withstand the enormous force of fast-moving water. The most common method of installing the rocks has been to reslope the bank or levee (cut back the vertical or near-vertical portion of the area to a gentler slope so the rocks will remain in place), and then to place the rock on the newly-cut slope from the toe to the highest level the water is expected to reach. A broad-base herbicide is then applied to prevent the growth of trees, brush, and other vegetation that might dislodge the rock or prevent the slope from being thoroughly inspected.

Spraying truck with twin booms being readied for application of spray.

New Directions

After the major floods of December 1955 in Northern and Central California, maintenance work was stepped up. Levee inspection intensified, with emphasis on clearing brush and trees and other wild growth with chemicals and fire. Often, nearly all vegetation was removed. It was this type of maintenance, along with the use of rock bank protection, that aroused strong protest from environmentalists, the general public, and many public officials. The press of public dissatisfaction, coupled with a wakening consciousness of the environment, brought about studies to find acceptable alternatives to levee stripping. Their findings have led to some recent modifications in maintenance.

As the Department saw how current channel clearance methods were affecting the environment, it began to leave patches of trees and brush or strips of vegetation paralleling the direction of flow in floodways, at the same time complying with standards of the Corps of Engineers. Periodic clearing in this manner, with several intervening years of regrowth, has effectively covered banks with new growth.

In 1975 and 1976, the Department and the Corps of Engineers went to considerable length to reduce channel clearing requirements in the lower Putah Creek channel without sacrificing the integrity of the project. These changes, undertaken in cooperation with landowners along the project, were possible because Monticello Dam, lying upstream, cut streamflow from 1 756 to 1 132 cubic metres per second (62,000 to 40,000 cubic feet per second). The new minimum maintenance standards allow for some tree growth on levee slopes and on the first 15 feet of channel bottom from the toe of each levee bank toward the center of the flood channel. Channel bottoms were also cleared less often.

The Department's maintenance personnel keep abreast of the latest research and development in herbicides and pesticides. Every two years, DWR joins with other agencies in a training workshop required for all maintenance personnel responsible for pest (weed) control. Others involved are the U.S. Bureau of Reclamation, the Agricultural Extension Service at the University of California's Davis campus, and the State Department of Food and Agriculture. Continued efforts of this type will help preserve selected types of streambank vegetation.

Grader preparing a levee crown to provide an all-weather roadway, an especially important feature for inspecting levee slopes during winter floods.

Present Practices

Levee maintenance practices presently used by DWR include several new techniques aimed at easing the impact on scenic and recreational values. Some of the more important ones are:

Using mowers that can trim the steep levee slopes and move around obstacles. Although this is more costly than burning, the results are more acceptable to owners of adjacent lands and to those using the area for recreation.

Applying sprays that eliminate only undesirable plants. In addition, drift of herbicide sprays to nearby areas has been nearly ended by better control of application under varying weather conditions.

Halting the removal of large trees on oversized levees. Wherever practicable, the trees are trimmed or topped to allow levee inspection and to reduce the risk of windfall.

Improved burning practices. Burning is restricted to those days approved by the State Air Resources Board. Fires are guarded closely, and better fire-fighting equipment is used. These steps have reduced smoke and preserved desirable vegetation.

Stronger measures to ban unauthorized use of levee roadways and to control dust in urban areas. Use of oil and gravel to control roadway dust, although expensive, could be extended to agricultural areas where dust may encourage certain crop diseases.

Improved weed control spray program. For example, a newly developed spray material is being used to control Johnson grass on the levees. Although this spray costs two to three times more than conventional sprays, it does not have to be applied as often.

Rock riprap newly placed by the Corps of Engineers on a levee slope along the Sacramento River near Walnut Grove, Sacramento County. Partial coverage of the bank typifies the Corps' current levee construction practice.

The Search for Better Methods

Several studies have been conducted to find even better approaches to levee maintenance — in particular, alternatives to protecting levee embankments with rock.

In 1961, when controversy arose over the single-purpose maintenance that was removing vegetation from levees in the Sacramento-San Joaquin Delta, the Sacramento River and Delta Study Committee recommended that certain reaches of levee be selected to test various types of vegetation, determine appropriate methods of control, and learn what these types of maintenance would cost. In June 1967, DWR published Bulletin No. 167, "Pilot Levee Maintenance Study", which concluded that, with a proper vegetative management program, the esthetic, recreational, and wildlife values of certain Delta levees could be preserved, without impairing their flood control function.

Also in 1967, the Corps of Engineers and The State Reclamation Board joined in an experiment that involved replanting 3 450 metres (11,500 feet) of levee berms and slopes along the Sacramento River about three kilometres (two miles) north of the Sacramento Weir, above the City of Sacramento. This project was carried out because both agencies were interested in introducing esthetic considerations into levee construction and modification and in extending the 1961 study by the River and Delta Committee. The program was costly, and only half the plantings survived. Fire, floods, and lack of irrigation destroyed the rest.

In June 1971, the Corps planted a variety of trees, shrubs, grasses, and ground cover in a test site along 792 metres (2,600 feet) of the waterside levee slope along the right bank of the Sacramento River upstream from Elkhorn Ferry, north of Sacramento. The idea was to develop a vegetative cover requiring minimum maintenance. This experiment also failed. After watering stopped, the plants died.

The Corps also experimented with various trees, shrubs, grasses, and ground cover planted on approximately 1 200 metres (4,000 feet) of waterside slope and berm of the

Riverbank trees with exposed roots often jeopardize the stability of banks and levees. Many of them can be saved if they are topped and pruned.

levee at five sites on the right bank of the Sacramento River, downstream from the City of Colusa. This vegetation was planted by direct seeding and watered only until the seeds germinated. Once again, the results were not encouraging. Most of the vegetation died.

In recent years, in connection with the Sacramento River Bank Protection Project, the Corps selected certain levee sites to preserve native trees and brush. These areas are now a part of the present maintenance program.

In Sacramento County, the prohibition of burning and problems relating to the drift of herbicide sprays have called for different techniques in the urban areas around the City of Sacramento. A test site 0.8 kilometre (0.5 mile) long was selected in the spring of 1974 along the right bank of the American River immediately downstream from the Watt Avenue Bridge in Sacramento. Seven types of ground cover were planted on the landward levee slope, and a sprinkler system was installed. The site was watered frequently during the summers of 1974 and 1975. Since then, the plantings have been checked to see how well they are growing without water. Success has been minimal, and vandalism has recently become a serious problem. Only three varieties of ground cover show any sign of surviving without summer watering — lippia, St. Augustine grass, and capeweed.

Badly eroded levees are an exception to current methods. No practical or economic alternative to rock bank protection has been found to repair them or to prevent erosion at and below normal water levels. However, some maintenance has been modified. Now only selective herbicides are used on rock-covered areas so that some native vegetation will remain.

The recent trend toward modifying levee and channel maintenance practices has allowed room for more consideration of the environment. However, much more can and must be done, if an acceptable balance is to be found. Insensitive maintenance practices can destroy valuable stands of streamside vegetation that take 30 or more years to mature. Even where the denser growth cannot be permitted, the narrow ribbons of plant growth can be encouraged, providing both esthetic and functional value.

Low-growing vegetation planted along Sacramento River levee slopes north of Sacramento are watered by an aboveground sprinkler system.

The Course for the Future

The Department of Water Resources is actively developing environmentally sound maintenance practices, thus setting examples for the thousands of local maintenance agencies in California to follow. Some modifications that DWR proposes can be put into action over the next few years, some can be used immediately, and some will require further study or additional funding.

Dams built on four major tributaries to the Sacramento River in the last 14 years might enable the Department to modify its flood control maintenance program in ways that will allow more vegetation on flood control structures. The Department will continue to work for agreement with the Corps of Engineers on ways of changing the maintenance standards for these streams to permit adoption of more environmentally sensitive programs. The streams and projects are:

- Bear River: Camp Far West Dam (1963) and Rollins Dam (1965)
- Feather River: Oroville Dam (1968)
- Yuba River: New Bullards Bar Dam (1970)
- Cache Creek: Indian Valley Dam (1976)

With the approval of the Corps, this program could be put into effect in the near future. The same approach should be followed for streams below future dams.

The Department will use clearing methods (such as selective herbicides and clearing in strips parallel to flow patterns) that will leave as much undisturbed vegetation as is consistent with the Corps' requirements. The frequency and pattern of clearing will be reviewed to determine whether beneficial adjustments can be made.

The Upper Sacramento River Task Force, led by the State Resources Agency and made up of a number of State and federal agencies and other concerned organizations, is proposing a program to protect the streambank forests in the flood plain along the Sacramento River. This would prevent some of the levee clearing now going on, particularly by private interests. This group is also reviewing the Corps' requirements and the Department's responsibilities to keep clear the many sites that the Corps has cleared in the Sacramento River channel between Colusa and Princeton. The group will probably propose some changes in methods and frequency of clearing. When the task force recommendations are available, the Department will use them to guide and modify its maintenance work.

Where Practices Can Be Altered

Certain levee maintenance and repair practices can be changed with funds currently available. These are activities DWR plans to undertake:

Make greater use of mowing, rather than burning. First priority will be assigned to urban areas. Where necessary, areas will be mowed more than once during the growing season to reduce fire hazard to adjoining property.

Continue to improve methods of selecting and applying herbicides to retain as much native vegetation as possible consistent with flood control.

Continue control of some burrowing rodents by eliminating such unnatural habitat as prunings, debris, and refuse deposited on levee slopes.

Extend the new program of oiling roadways on levee tops to urban areas.

Assess low-growing plantings along the American River in Sacramento, and consider revegetation as a way of solving problems that accompany spraying, mowing, burning, and dragging operations.

Curtail the practice of sterilizing rock revetments, and allow vegetation such as joint grass, ice plant, and grasses to grow over the rock. Undesirable growth will be controlled with selective sprays and/or cutting. This program will be carried out on the 88 kilometres (55 miles) of rock-covered levee banks now maintained by DWR on various Sacramento Valley streams.

Promote revised clearing requirements to leave as much vegetation as possible, taking into account construction requirements. DWR will request that, before a levee is built, native streamside vegetation at each site be inventoried and a site plan developed by the agency responsible for construction to retain as much of the vegetation as practicable.

Other changes in levee maintenance and repair programs will need additional study to test their suitability.

Levees and banks to be covered with rock could be terraced at intervals, the rock placed on the embankment slopes, and vegetation planted on tops of the terraces.

Where streamflow velocities are not excessive and a levee is oversized, the levee slope might be faced with rock only to normal flow levels, instead of to flood level.

Erosion in environmentally imperiled areas could be repaired by waterborne equipment before major resloping is necessary.

In some places, the landward slopes of levees might be reshaped to accommodate mowers or other maintenance equipment. In this way, native vegetation could be retained in areas where this is not now practicable.

A program to support irrigated revegetation could be supported. In urban areas, adjacent landowners could be assisted with the cost of this work, in line with DWR's new landscape design standards for saving water.

California's rivers support populations of aquatic mammals, some of which (especially beavers and muskrats) work from the water side of a levee to dig burrows that can endanger its structural integrity. Unlike other burrowing animals, such as ground squirrels, however, beaver and muskrat burrows are less damaging because these animals dig only a short distance into a levee bank. As more levees are faced with rock, beavers and muskrats are driven elsewhere because they are prevented from burrowing and the streamside plants they feed on are no longer there.

Some means must be found to allow beavers and muskrats to continue inhabiting California's valley streams and yet retain the stability of the flood control embankments. One possibility is to place 0.6-metre (2-foot) lengths of concrete pipe in the rock perpendicular to the bank and below low-water level. These will provide access to animal burrows. Other access routes, such as small bays in the levees, may also be worth consideration. None of these procedures will impair the ability of levees to withstand flood flows.

The introduction of fresh ideas to channel and levee maintenance can bring us closer each year to achieving the sought-after balance between strong, effective flood control and preservation of important environmental values.

Information for this article was contributed by Robert R. Middleton, Jr., Chief, Flood Control Maintenance Branch, Sacramento

> Effectiveness of maintenance of about 2 720 kilometres (1,700 miles) of levees operated under State and federal agreement in Sacramento and San Joaquin Valleys and Lake and Placer Counties is reported annually by DWR. Results of yearly inspections of these levees appear in "Flood Control Project Maintenance and Repair" (Central District Report, free). This information was previously published in the Bulletin No. 149 series under the same title.

Trees planted on a Sacramento River levee bank in Yolo County five years earlier are growing well. This scene occurs near the site of the one-time Elkhorn Ferry crossing

The San Fernando Earthquake...

A Close Call Brings Safer Dams For California

At six o'clock on the morning of February 9, 1971, an earthquake of moderate strength shook a large area of the San Gabriel Mountains in Los Angeles County immediately north of the densely populated San Fernando Valley. Although the shock registered only 6.4 on the Richter scale of earthquake magnitude, damage was remarkably severe. Fracturing and lurching of the earth caused a number of large buildings and several elevated freeway interchanges to crumple to the ground, and power and water treatment facilities and other public utility services were seriously disrupted. Ruptured earth and shattered street paving were common along the earthquake fault in the communities of San Fernando, Sylmar, and elsewhere. The slope of a major water supply tunnel then under construction in the San Gabriel Mountains tilted more than 2 metres (6 feet).

Although Californians expect earthquakes from time to time in many parts of the State, the San Fernando earthquake came as a real surprise. For one thing, the existence of the fault on which the movement occurred was unsuspected, and, for another, in the 12 to 13 seconds the shaking lasted, the ground shook with unprecedented intensity — far greater than had previously been measured for such a moderate earthquake.

An ominous aftermath was the precarious condition of two large hydraulic fill earth dams overlooking the valley. The Upper and Lower San Fernando Dams, along with a smaller dam, form the Van Norman Reservoir complex, an important part of the water delivery system for Los Angeles. When the earthquake struck, both dams were greatly affected. Control towers fell or tilted, and access bridges were lost.

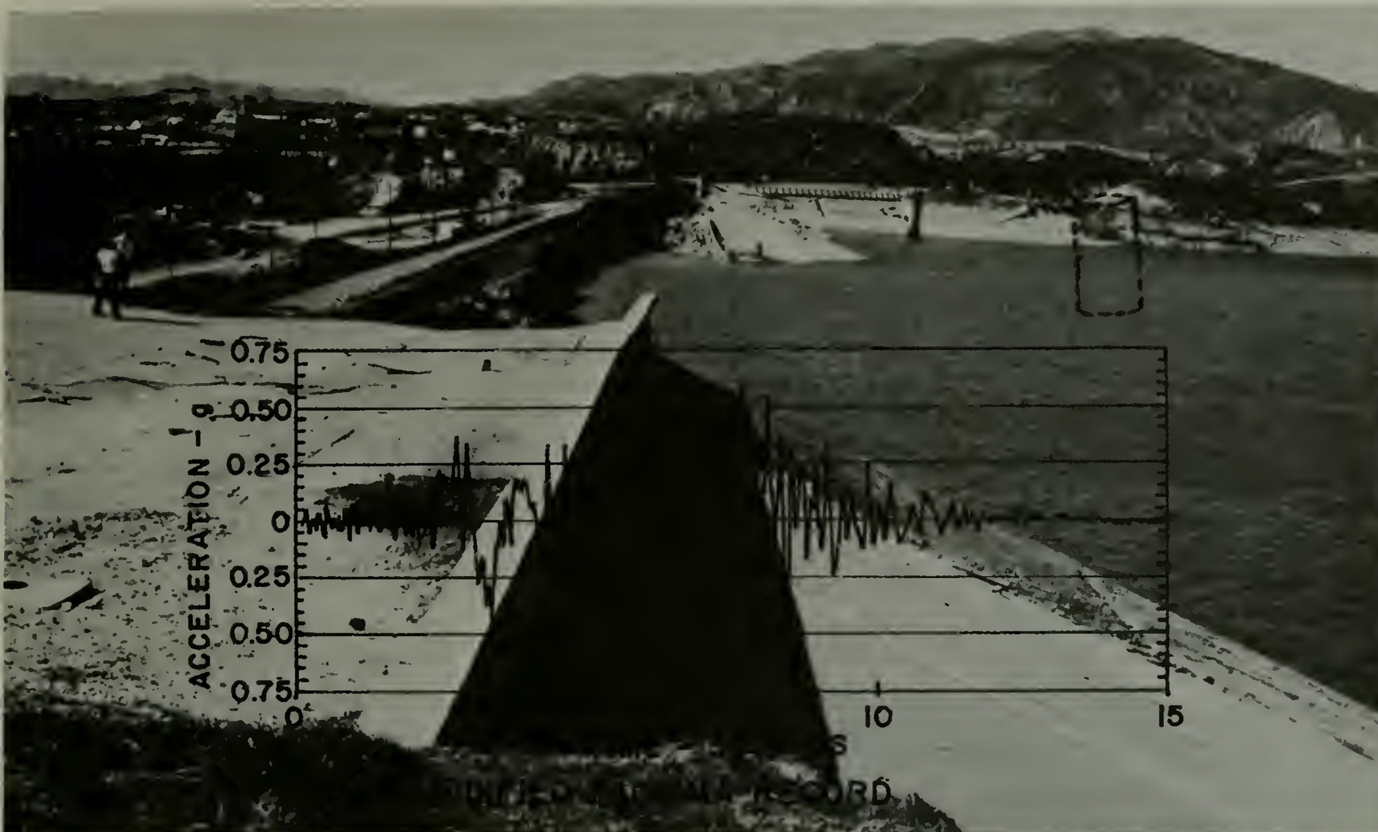
But by far the most dramatic incident was the collapse of a major part of the upstream portion of the 43-metre-high (140-foot) Lower San Fernando Dam, including the topmost 9 metres (30 feet) of its crest. An estimated 610,000 cubic metres (800,000 cubic yards) of earth slipped into the Lower San Fernando Reservoir. When the earth slide came to rest, just 1.5 metres (5 feet) of dam remained above the reservoir. This was the only thing that kept a wall of water from crashing down on some 80,000 people living in the valley below the dam. A series of aftershocks that followed the main shock placed the valley in great jeopardy. Reservoir draining was begun immediately, and residents were evacuated from the valley. They were allowed to return four days later when the reservoir level had been lowered sufficiently to avert the danger of flooding.

Investigation later disclosed that if the earthquake had lasted a few seconds longer, or if the reservoir had not been operating well below its full capacity, the dam might very well have failed completely, causing great loss of life and property.

Damage to the Upper San Fernando Dam was less spectacular. The 530-metre-long (1,750-foot) crest of the dam, which is slightly more than half the height of the lower dam, slumped about 1 metre (3 feet), and the entire embankment shifted about 1.5 metres (5 feet) downstream. Several large longitudinal cracks appeared in the concrete paving on the waterside slope of the dam, and water began leaking from the base of the structure. The water in this reservoir was also lowered as a safety measure.

The third storage dam, the Lower Van Norman Bypass Dam, is a relatively small structure adjoining the Lower San Fernando Reservoir. Completed in 1970, the dam is a well-compacted earth-fill facility

Lower San Fernando Dam on February 12, 1971, three days after the earthquake. The approximate previous location of a toppled outlet control tower is shown by the dotted outline.



built to modern standards. Aside from superficial cracking of the reservoir's asphalt concrete lining, this dam rode out the earthquake without damage, and its operation was entirely unaffected.

Search for the Cause

Exhaustive investigation into the reasons for the near-failure of the Lower San Fernando Dam and the serious damage sustained by the Upper San Fernando Dam was carried out by Professors H. Bolton Seed of the University of California, Berkeley, and Kenneth L. Lee of the University of California, Los Angeles. The study they directed was supported jointly by the Department of Water Resources, the Los Angeles Department of Water and Power (owner of the Van Norman Reservoir complex), and the National Science Foundation.

Seed and Lee determined that the cause of the movement of earth in both dams was liquefaction, a phenomenon that occurs when a nonliquid substance acts temporarily as if it were a liquid. In the case of the San Fernando Dams, the violent shaking of the earth momentarily transformed portions of the sand materials in the dams into near-liquid masses. This was demonstrated by the condition of certain structural parts at both sites and by the manner in which the great masses of material at the Lower San Fernando Dam slid into the reservoir.

The reason for failure was apparent, but, at the outset of the investigation, the mechanics of the earth movement were not entirely understood. This was an opportunity to test how applicable the technique of vibration analysis of earth dams was to the performance of these two dams. The slope failure at the lower dam provided a particularly invaluable testing ground. The investigators found that these structures were vulnerable to earthquake damage because the hydraulic fill sands they were composed of had a relatively low density — on the average, about 54 percent relative density. (By comparison, compacted sands in modern dams have a relative density greater than 70 percent.) Their studies demonstrated the inadequacy of conventional methods of analyzing the seismic stability of slopes.

When the investigation was complete, one fact stood out clearly: the behavior of the San Fernando Dams during an earthquake could be reasonably simulated, using analytical techniques that were being developed at the time of the shock.

Hydraulic fills are now known to be characteristically susceptible to damage from earthquakes. The Dry Canyon Dam in Los Angeles County and Haiwee Dam in Inyo County were seriously affected by the 1952 Arvin-Tehachapi shock in Southern California, although both were situated far from the epicenter of the earthquake. Both exhibited the longitudinal embankment cracking that was magnified many times at the San Fernando Dams in 1971.

Judging by these and other manifestations of severe seismic shaking, dams built of hydraulic fill are most likely to be distorted by low-frequency vibrations lasting a comparatively long time. The result is settling and lateral spreading, which is intensified when liquefaction occurs, as at the San Fernando Dams.

Elsewhere in the State . . .

Of the more than 1,100 dams operating in 1971 under the jurisdiction of the State of California, 35 were hydraulic fill structures. The San Fernando experience provided a compelling incentive for investigating the stability of these dams. It was apparent that what happened there could happen elsewhere in the State. Thus the field of investigation widened.

In December 1971, while the San Fernando investigation was still going on, the Department of Water Resources directed the owners of nearly all dams in California believed to be hydraulic fills to examine these structures for their ability to withstand damage from earthquakes of the maximum credible size for the area. The owners were to use the latest analytical methods available. Depending on the relative hazard in each case, they were given one or two years to complete the work.

With few exceptions, the owners responded readily. The most vulnerable dams and reservoirs were large storage projects located near San Francisco and Los Angeles, both highly seismic areas. These projects are owned and operated by major municipal utilities fully supported by technical staffs. Recognizing the potential liabilities facing them, these agencies acted quickly to begin their investigations. Those dams whose failure would cause the greatest havoc were generally studied first. By 1977, nearly all investigations had been finished.

Some of the most competent specialists available in the field of earthquake and dam engineering performed the work. Not all the dams needed thorough analysis. Less rigorous procedures were acceptable when it could be determined the dam was clearly stable or unstable. If any doubt regarding its stability existed, a complete seismic (dynamic) analysis was carried out.

In general, it was found that many hydraulic fill dams in California needed to be replaced or substantially modified. Some, however, are situated in areas where intense seismic shaking is unlikely and were found to be stable. These dams presented no danger and continue to operate.

Several hydraulic fill dams were located in areas that necessitated their analysis under two earthquake sources — a large magnitude event occurring some distance away on the San Andreas fault and causing long-duration shaking, and a lesser event of relatively shorter duration occurring on a local fault. The smaller earthquake would develop greater ground accelerations (shaking) at the dam site than the large earthquake. In all cases, the effects of the long-duration San Andreas shaking would equal or exceed the effects of the shorter, more intense local disturbance. The reason for this is the cumulative effect of the long-duration shaking on loose soils.

Most of the California dams that investigation disclosed were inadequate provide essential municipal water supplies. In each instance, the level in the reservoir has been lowered as far as possible without interferring with regular service. Several reservoirs are operating with severe storage restrictions, and some have been drained, pending decisions on their eventual disposition.

San Pablo Dam in Contra Costa County, a full hydraulic dam under construction. The structure was completed in 1920.

Several years must pass before all these dams are restored to full service or replaced. Some may even have to be abandoned. Lack of funding is one of the paramount problems.

The impact of these findings on hydraulic fill dams in California has been enormous. It has been a dominant factor in the State's total program of dam safety, and it has also caused financial and operational problems for the water service utilities that operate these dams. The greatest long-range significance, however, lies in the new knowledge these investigations have brought to the engineering profession. Methods of seismic analysis are now available to analyze the safety of earthfill dams in a much more realistic fashion than was previously possible.

Development of the Hydraulic Fill Dam

Earth dams built in California by the hydraulic fill method were primarily an American development that evolved into accepted principles of design and construction. More than 30 relatively large dams were built between 1850 and 1940, most of which were still in use at the time of the San Fernando earthquake.

The hydraulic fill method grew out of practices followed in hydraulic mining, which was widely used in the western United States in the late 1800s. Gold-bearing sand and gravel deposits were broken down and moved by directing heavy streams of water under extremely high pressure against the deposits. The idea was to move large quantities of such material through devices which recovered the gold. It was found the hydraulic process could be used to build reservoir-forming dams that supplied the great amounts of water needed for hydraulic mining. In this way, large amounts of material could be economically transported with simple equipment.

The true hydraulic fill dam was built by conveying earth materials from the excavation site to the dam site as a liquid mixture and placing it directly on the top of the embankment. The intent was to achieve a gradation of materials ranging from an impermeable core composed of fine-grained soils to a free-draining outer shell composed of coarser soils and gravels on the upstream and downstream slopes of the dam. This composition was often achieved when the right material was available. The coarser materials would settle at the outer edges of the embankment soon after the slurry was deposited, and only a muddy mixture was left by the time the slurry had traveled to the center. The finer soils remained in suspension for a longer time. The core remained in a semiliquid state for many months, slowly consolidating and gaining stability.

Preliminary geologic exploration of dam sites was sometimes minimal in the earlier days, and builders often had to proceed

Haiwee Dam in Inyo County, showing the semihydraulic method of construction. It was completed in 1913.

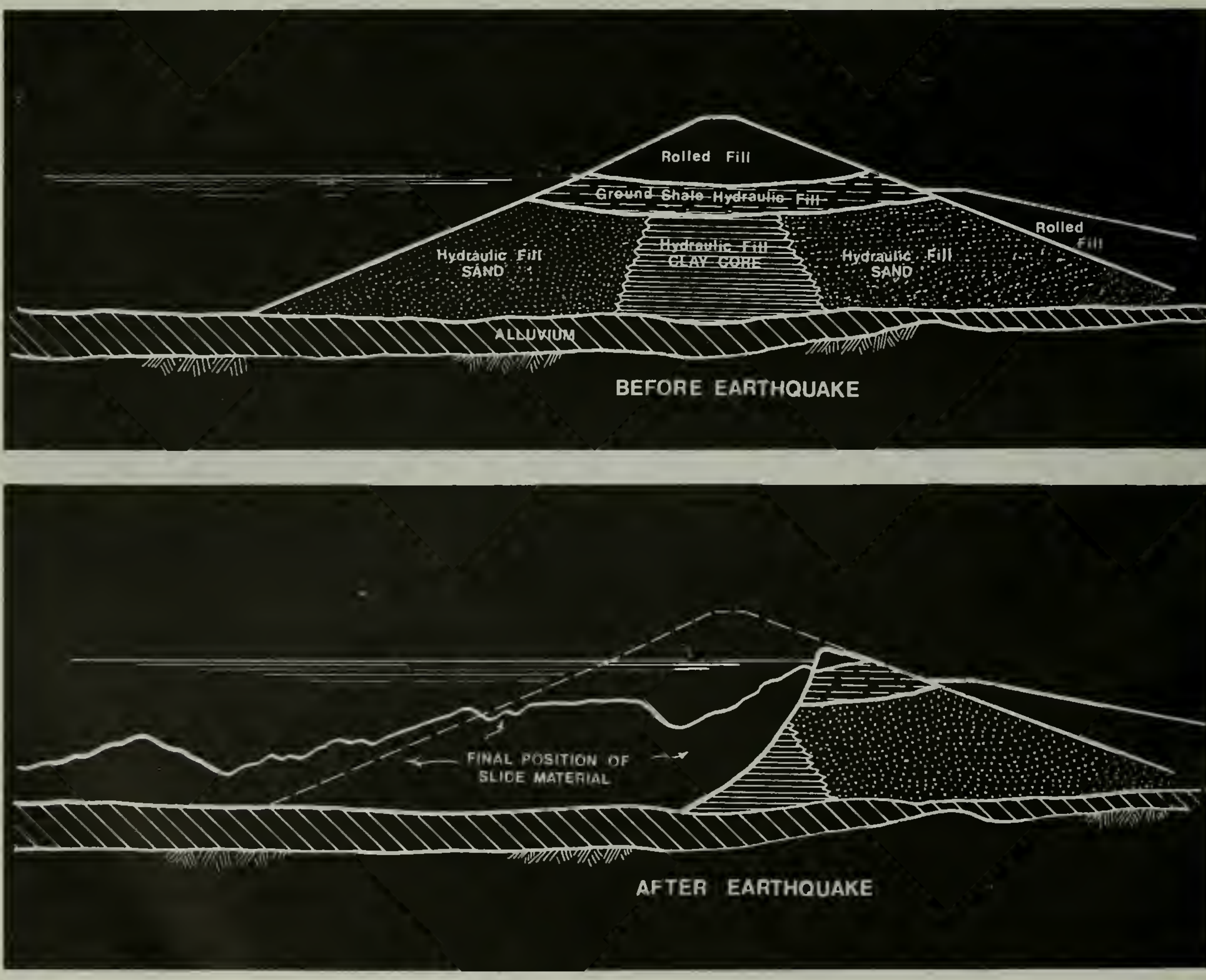
without full information about the underlying native materials. Many problems later associated with hydraulic fill dams were direct outgrowths of this and other early construction practices.

Various methods were used to excavate the material for the dams, including shovels, draglines, dredges, and hydraulic monitors, large water-directing nozzles like those used in hydraulic mining. In a typical situation, the monitor was pointed toward the excavation to undercut and break up the material. The resulting liquid mix of water and earth (slurry) was then moved into flumes or pipes that carried it to the construction site. In some cases, the material was excavated by suction dredges and pumped to the site by pipeline. Flumes or pipes at the dam faces directed the slurry toward the center of the work area on the top of the rising dam embankment.

The semihydraulic method, an alternative to the true hydraulic fill, was developed for use at sites where little or no water was available to transport the dam-building material. The soils were usually hauled to the dam by horse and wagon or railroad car and dumped along the outer edges on top of the embankment. Material from the inner face of the dumped fills was then sluiced toward the center of the dam by water jets. The finer material washed into a central pool, forming the core of the dam, and the coarser particles tended to settle closer to the face of the dam. The outer face of the dumped fill was not affected by the water jets and was often more dense and impervious than the material immediately adjoining the dumped fill on the inside of the dam. Contrary to the builder's intent, this tended to hold water within the embankment, contributing to some cases of failure.

A general rule in building hydraulic fills was that the shell should be many times more porous than the core. This ratio has been reported to have ranged up to several hundred times. The methods used in building semihydraulic dams contributed in some cases to construction failures by holding water pressures in the interior of the embankment too high for safety.

One type of hydraulic fill dam that is expected to stand up well to earth tremors is one in which the soils are cohesive, or clayey, and relatively compact. The Hawkins Dam in San Benito County is a good example. The satisfactory behavior predicted for this dam during severe ground motion agrees with the way in which a



number of conventional dams made predominantly of clay survived the 1906 San Francisco earthquake with little damage.

Problems in Performance

By the 1920s and 1930s, hydraulic fill construction was beginning to be regarded with disfavor. Some engineers became concerned about its general deficiencies when a series of slides and construction failures took place. Although both the true hydraulic and semihydraulic fill dams have been known to suffer from excessive settlement, dams built by the true hydraulic method were relatively free from mishaps. However, several semihydraulic fill embankments experienced sliding during construction. At one old dam of this type, the core was found to have settled so much that reservoir water was passing between the capping material and the central zone of the embankment.

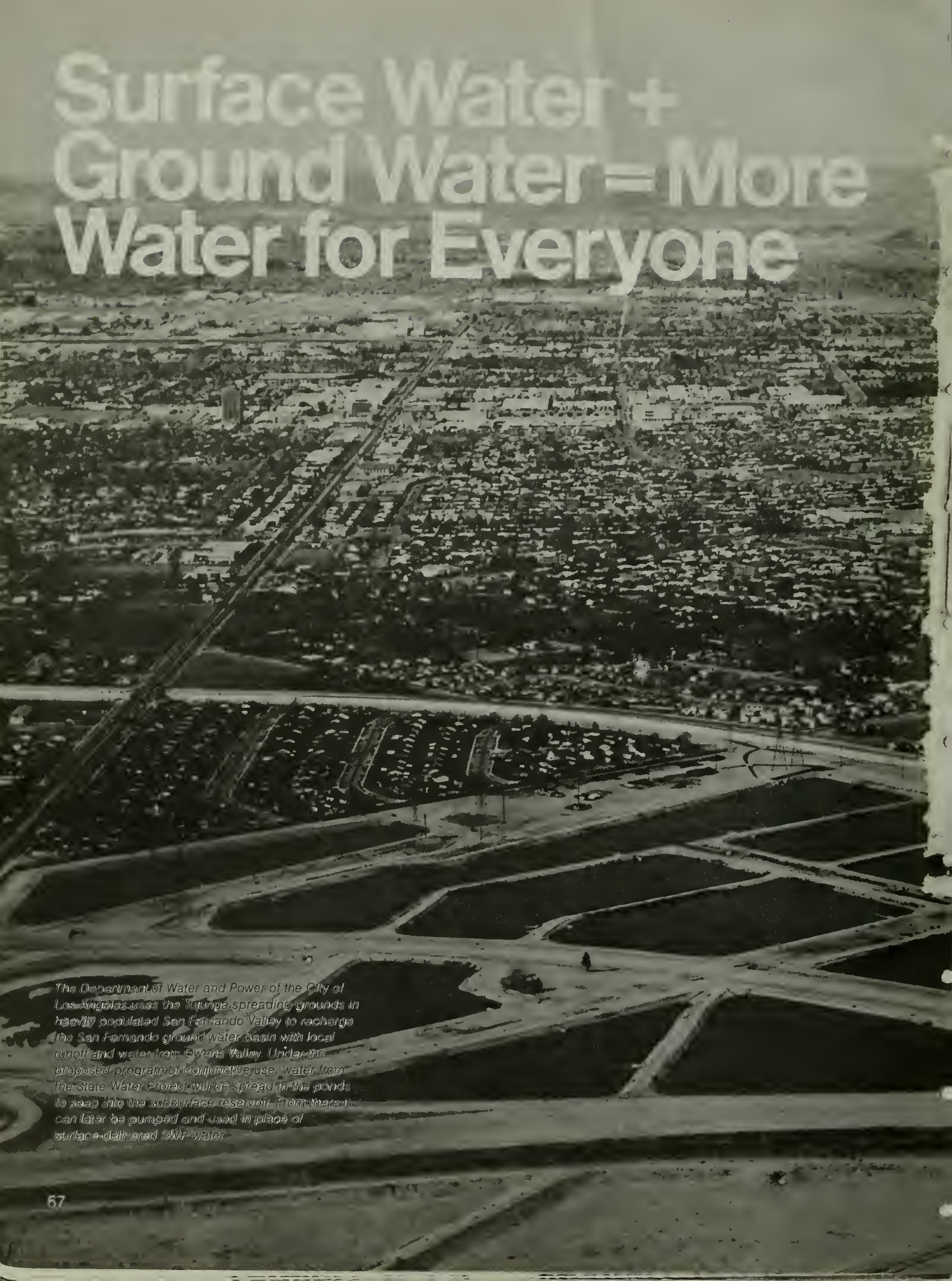
A core that would stop the passage of water was originally regarded as an especially favorable attribute of these structures. However, all hydraulic fills were not as impervious as their builders expected them to be. Examination of borings at old dams has revealed uniformly-graded sand or sandy silts within cores having undesirably high permeability, and some cores have been found to be dangerously laminated. These conditions would easily lead to internal erosion and ultimate leaking, particularly in a highly saturated embankment.

After the massive slide in 1938 during construction of the Fort Peck Dam in Montana, the whole concept of hydraulic fill construction became highly suspect. Even though the Fort Peck failure was finally blamed on an inadequate foundation rather than on unstable embankment material, this event marked the decline of such building methods. The advent of heavy compaction equipment in the 1940s brought to the fore the rolled embankment as an alternative construction method. Since then, hydraulic fill has not been seriously considered for new construction. It remains, however, as a fact of continuing interest to engineers who are responsible for ensuring the safety of the many hydraulic fill dams still being used in California.

Information for this article was contributed by Keith G. Barrett, Chief, Design Branch, Division of Design and Construction (formerly with the Division of Safety of Dams), Sacramento.

Calaveras Dam in Alameda County, showing earth slide that occurred on the upstream side during construction. The dam was completed in 1925.

Surface Water + Ground Water = More Water for Everyone



The Department of Water and Power of the City of Los Angeles uses the Tujunga spreading grounds in heavily populated San Fernando Valley to recharge the San Fernando ground water basin with local runoff and water from Owens Valley. Under the proposed program of conjunctive use, water from the State Water Project will be spread in the ponds to seep into the subsurface reservoir. From there it can later be pumped and used in place of surface-delivered SWP water.

Ground water — water below the earth's surface that is caught and held by nature in sand, clay, and gravel deposits — is a rich source for California. Immense reserves of such water lie beneath many parts of the State. These underground reservoirs have been tapped for many decades to supplement surface water supplies. Some water service agencies have gone considerable distances to obtain ground water. About 80 years ago, the Spring Valley Water Company, which then served the City of San Francisco, developed well fields to pump from ground water basins under the Livermore and Sunol Valleys, about 45 miles east of the city, and the City of Los Angeles extracted water from basins in Owens Valley to supplement Owens River supplies, starting in 1918.

Agencies have also drawn on ground water reserves in their own areas for at least the past 40 to 50 years. This has occurred widely, particularly where extensive urban or agricultural development has created a heavy demand for water. Some notable examples are Sacramento, Yolo, and Alameda Counties and Santa Clara Valley in Northern California; the east side of San Joaquin Valley; and Ventura and Orange Counties and San Fernando Valley in Southern California. In these instances, water from wells was often used to satisfy demand when streams and reservoirs were unable to do so.

However, in recent years, there has developed a growing recognition of an even richer source: the *combined* use of water from both ground and surface. The technique, known as conjunctive use of surface and ground water, is an economic and efficient way of meeting the need for water through carefully planned management. It means making the maximum use of available water, a concept that has come to have increasing importance, particularly in this drought period. The amounts that result from conjunctive use, in fact, can actually be greater than the amount obtained by developing surface and ground water supplies separately and then combining the output.

As used in studies being undertaken by the Department of Water Resources, conjunctive use essentially means bringing water from some surface source and letting it seep through the earth into a ground water basin, where it remains until it is pumped back to the surface. The idea behind this process is to store water not needed when supplies are plentiful and withdraw it when they are short. To be successful, conjunctive use demands a logical and orderly plan that draws not only on long-term hydrologic experience and thorough geologic information, but also on a host of other disciplines and philosophies sometimes far removed from the physical sciences.

Two methods are commonly used for introducing surface water into a ground water basin — direct recharge and in-lieu recharge. Both are called artificial or planned recharge — meaning they are brought about by human effort, not by nature. (Natural recharge occurs whenever rain or melting snow soaks naturally into the earth.) In the direct method, water is brought (imported) to the area above the basin and allowed to flow, or spread, onto a large piece of land set aside for the purpose, called a spreading ground. The water seeps gradually down through layers of soil and rock and moves very slowly into whatever openings it finds among them. This action eventually raises the ground water table. While rates will vary from basin to basin, water being spread disappears into the ground at an average of about 0.3 metre (1 foot) per day, although one unusually productive basin in Ventura County is famous for accepting water at the rate of 1 metre (3 feet) a day.

The in-lieu method of recharge is actually a type of trade-off. Water that would have been spread to recharge a basin is instead delivered to a water service agency that in turn delivers it to its customers. An equal quantity of native ground water and recharge water the agency would have pumped from the basin is allowed to remain in the ground, and title to it is transferred to the agency.

There are two sides to the picture in both recharge processes. No costly electrical energy must be spent to pump the water out at the time the water agency receives the imported surface water, but it must be spent ultimately when water is withdrawn. (The cost of pumping is a very real factor in the use of ground water, and all present estimates point to much higher costs in the future.) Also, surface water may have to be chemically treated to make certain it is suitable (pure enough) for the use to which it will be put. On the other hand, the ground water is improved from having filtered through overlying sedimentary rocks, and chemical treatment is, for the most part, unnecessary.

The direct recharge method requires the allocation of large areas of land solely for spreading the recharge water.

In either method, the ground water basin must be physically equipped with wells and pumps, and its hydraulic characteristics must be fairly well known.

The very flexibility of a conjunctive water operation makes it extremely useful. A ground water storage project does not have to be committed to only one type of recharge. In fact, judicious use of all methods can be most helpful at times. Even though a water treatment plant or a spreading ground may have to be taken out of service for maintenance or some other reason, recharging can continue.

How the Concept Evolved

Historically, ground water and surface water have been used separately in California. A decision to draw on either was often based on such simple considerations as cost or availability. During the spring, when streams were usually running full, surface water was generally cheaper and easier to obtain, and ground water basins, many of which had been lowered by pumping the previous year, were being fed by natural seepage from rainfall and snowmelt. In the summer and early fall, when no rain fell, as a rule, and streamflow diminished or ceased entirely, water was available for pumping from the replenished basin.

Hundreds of dams, both great and small, were erected in California between 1870 and 1970 to conserve the springtime floodwaters that once flowed unchecked to the ocean and to prolong the period in which surface water could be used. Then gradually, as the best dam sites were taken, and techniques for drilling deeper and deeper wells improved, ground water use increased. In some parts of the State, people began to see that water could be stored below ground, as well as be withdrawn from it, and basins whose levels had been lowered by pumping were used to hold excess water.

Despite the long history of surface water development and the expanding use of ground water, however, for some time these were considered separate and distinct functions. The idea of using them together was a long time in coming. Not until the 1950s were projects designed and built with the intent of conjunctive use. Santa Felicia Dam in Ventura County and Twitchell Dam in San Luis Obispo County are two examples of such planning. Both were built to store water for later recharge of ground water basins.

Although multiple-purpose regional and inter-regional water development works such as the State Water Project and the federal Central Valley Project are now firmly established, until quite recently the influence of some of the earlier limited approaches to water planning was still being felt. As an example, the State Water Project was designed in the 1960s in accordance with the water development philosophy that emphasized multiple use and maximum benefits in relation to cost. Yet the entire yield of the first phase of the project was designed to come from a series of surface works — dams and reservoir, river diversions, canals, pipelines, pumping plants, and power plants. Consideration was given to the possibility of using ground water basins for regulatory storage, but nothing came of it at the time because of uncertainties over ground water rights and possible conflict with local ground water management plans.

Since the initial demand for water from the State Water Project was expected to be only a fraction of the ultimate demand, many of the early facilities were not built to deliver full SWP yield. This was consistent with rational, economical planning. To keep pace with a planned increase in demand over the years and to finally provide the Project's full yield years hence, the State planned to build a series of dams and reservoirs as they were needed. All future efforts were also tied to futher surface water development.

Beginning in the latter half of the 1960s, when the construction of the first phase of the project was in full swing, great changes began to take place throughout the country. A growing segment of the population began viewing established social and environmental structures with skepticism, and long-accepted premises were given searching and critical appraisal. The quality of life and the effects of our increasing population and economy on our natural resources and environment emerged as issues of burning importance.

The influence of this new concern for the disposition of our resources was reflected in the enactment of the Wild and Scenic Rivers Act in California in 1972 that prohibited construction of dams on major streams in the north coast region of the State.

The Wild and Scenic Rivers Act and a series of other State, federal, and local actions made clear that new approaches to meeting water needs would have to be explored before additional natural resources were committed.

Among those approaches awaiting study was the conjunctive use of water. However, many matters other than physical problems must be resolved, before a commitment is made to proceed with conjunctive use in any particular location.

The Question of Legal Authority

Until very recently, the success of long-term ground water storage was clouded by doubts surrounding the legal right to use ground water and the unused storage capacity in a ground water basin. The rights to store imported water underground, to maintain ownership of that water while it was in storage, and to recapture the water as needed were not well defined.

Two recent court decisions, *The City of Los Angeles* v. *City of San Fernando* and *Niles Sand and Gravel Company, Inc.* v. *Alameda County Water District*, removed most of those doubts. In the Los Angeles case, the City of Los Angeles made two claims: first, it asserted a "pueblo right" to all native ground water (water resulting from precipitation) in the San Fernando Basin beneath the San Fernando Valley, and second, it asserted its right to ground water derived from imported water. (Pueblo rights were those conveyed to Los Angeles as the inheritor of rights granted under Spanish and Mexican law.) The court upheld the claim made on the basis of pueblo right.

More important from the standpoint of conservation storage, the court held that Los Angeles, as well as other cities that import water, has a right to store imported water in the basin and recover that water later. This opinion did a great deal to clarify and confirm the right to store imported water under ground.

The principles derived from the Niles v. Alameda case bear directly on ground water storage rights. In this case, the Niles Sand and Gravel Company, Inc., was excavating material from a deep pit in a quarry it operated on the east side of San Francisco Bay within the boundaries of the Alameda County Water District. The water district had been importing and spreading large quantities of water to recharge an underlying ground water basin. Continuing recharge caused the water table to rise, and ground water entered the pit, interferring with quarry operations. The excavator pumped the water from the pit into San Francisco Bay and sued for the cost of pumping and damage to its operations. The water district in turn brought suit for the value of the water pumped out and wasted and asked for prohibition of such activity in the future.

The court decided in favor of Alameda County Water District, prohibiting Niles Sand and Gravel Company from similarly pumping and wasting water in future operations and dismissed its claims for damages. It called the obligations of owners of land overlying a ground water basin to use only their proportionate share of this water a "public servitude," recognizing that a public agency (in this instance, the water district) has a right to enforce these obligations. The court recognized the scope of its decision in the following words: "The issues to be decided in this case will affect all future replenishment programs . . ."

The decisions handed down in both cases have done much to establish the practicability of ground water storage projects in California from the standpoint of legal authority. They have also helped clear the way for conserving water through ground water storage.

Effects on the Environment

Use of a ground water reservoir significantly benefits the environment because it eliminates the need to build a surface water facility — a dam and reservoir, for example. As necessary and useful as dams are in some situations, their construction can cause considerable temporary disruption in the immediate locality, with the amounts of power needed, the materials and equipment that have to be moved in, and the great influx of workers to the site. Moreover, irreversible change occurs when a streambed is dammed to create a reservoir.

There are other benefits that come with storing water beneath the earth's surface. Little or no water is lost to evaporation, while water in a surface reservoir evaporates at a rate of 1 metre (3 feet) or more per year. Ground water storage also takes advantage of the high-quality water in springtime stream flows. When placed underground, this water is protected from contamination and is improved by filtering through overlying soil layers. Moreover, most of the land overlying the ground water body may be used for other purposes.

Another environmental asset is the safety and reliability of a ground water storage project. Aboveground water facilities can be damaged or destroyed by earthquakes, tornadoes, explosions, and other catastrophes. Such events have almost no effect on underground water.

One factor that calls for careful consideration in designing a storage project is the way water travels below ground. As water anywhere will do, ground water moves downward to fill space available farther below. As this occurs, some water may be lost if it is not carefully controlled. Other problems can develop in low-lying lands situated above a ground water basin in which the water table is unusually high. If water is added to such a basin, the level may rise close to the surface and damage buildings or interfere with other uses of the land. Wells, pumps, and spreading grounds can also disrupt land use at times.

Effects on Water Quality

Water quality in a ground water storage program presents a number of problems that are brought on by the conditions in a basin. Storage space available may range from nominal amounts to millions of acre-feet. Local water quality may range from excellent to brackish (very salty). The water may pass through the overlying goelogic formations easily or with difficulty. The water can originate as natural storm runoff, waste discharge, or planned recharge, or it can seep in from adjoining basins. These and other factors must be fitted into the equation that will help answer water quality problems in a program of conjunctive use.

Predicting the quality of the water that will be recovered from a ground water basin is not a simple task. Quality often depends on how much the percolating water and the water already in the ground become blended. The rate of mixing is affected by several factors — the kind of soils and rocks the water passes through, the slope of the ground water, the locations of wells, and the rate of pumping. Mixing usually takes place comparatively slowly. The surface water being introduced tends to take the shape of a mound that appears to move slowly downward as a fairly well-defined unit that retains its distinctive characteristics for a considerable length of time after reaching the water table. Successive periods of spreading with varying qualities of water create successive layers of water. When these are pumped back to the surface, their mineral constituents are often found to be relatively unchanged, and individual layers can frequently be identified by their characteristic quality.

The technique used to retrieve this water will determine whether each layer retains its individuality or whether it has become well mixed with other layers. If the well casings through which the water is pumped are packed with gravel and perforated throughout, considerable mixing can take place. If the perforations are carefully placed, relatively unmixed water can be withdrawn from a particular layer.

In designing a ground water storage plan, the quantities and qualities of native and imported water and the interaction of one factor with another must be established ahead of time. The basic consideration is: by how much will the improvement in quality outweigh the reduction in quality?

The complexity of such determinations has led to development of a process called a mathematical model, which is a way of using mathematical formulas to simulate the physical characteristics of a ground water basin. A model expresses a great deal of data in mathematical form that is then entered into a computer. The answers obtained indicate what quality of water will be pumped from a basin. Mathematical models will be useful in managing the quality of ground water to meet desired standards.

The Economic Pluses

Storing water in ground water reservoirs rather than in conventional surface facilities offers several economic advantages. One major advantage is the savings in capital expenditures. The costs of bringing water to a spreading ground, drilling the wells, and installing pumping equipment are estimated to be about only a fraction of the cost of building a dam and reservoir, which, in the case of a large project, can easily run into hundreds of millions of dollars.

Another benefit is the enormous amount of water than can be drawn on. Latest conservative estimates indicate that a San Joaquin-Southern California ground water storage program could provide annually at least 690 cubic hectometres (560,000 acre-feet) to the State Water Project — more than 10 percent of the maximum amount the project was designed to provide. Making use of this water would mean constructing canals and channels to transport it from SWP facilities to the spreading grounds, and wells and pumps to recover it. The costs of this work can be weighed against costs of a surface project yielding the same amount.

Still another very sizeable benefit will result from the higher ground water table that will exist while the water remains below ground. A preliminary estimate showed that a typical Southern California basin could be exptected to rise, on the average, 30 metres (100 feet) when the surface water is introduced. With this increase and with pumps of customary size and efficiency, a savings in costs of about $5 per 1 200 cubic metres (1 acre-foot) would be realized at current prices for electric energy. Of course there are many capital and operating costs to be considered, such as construction of facilities to convey SWP water from the basin to the place of use, the cost of spreading the water, and other related costs.

A fair allocation of costs and benefits generated by a storage program will require thorough analysis. They will vary from basin to basin, and agreement on a reasonable assignment and distribution will be reached only after all the parties concerned have studied the situation. However, the net benefits should clearly justify the efforts needed to obtain them.

In recent years, DWR has covered the combined use of ground and surface water in a number of technical reports. They are listed below for those who are interested in learning more about the subject.

Bulletin No. 104-11, "Meeting Water Demands in Sacramento County," June 1975. $3.00

Bulletin No. 118, "California's Ground Water," September 1975. $3.00

Bulletin No. 118-1, "Evaluation of Ground Water Resources: South San Francisco Bay; Volume II, Additional Fremont Area Study," August 1973. $3.00

Bulletin No. 118-1, "Evaluation of Ground Water Resources: South San Francisco Bay; Volume III, Northern Santa Clara County Area," December 1975. $3.00

Bulletin No. 118-2, "Evaluation of Ground Water Resources: Livermore and Sunol Valleys," June 1974. $2.00

Bulletin No. 118-3, "Evaluation of Ground Water Resources: Sacramento County," July 1974. $4.00

Bulletin No. 118-4, "Evaluation of Ground Water Resources: Sonoma County; Volume I, Geologic and Hydraulic Data," December 1975. $5.00

What The Department Is Doing

In 1974 the Department of Water Resources completed a study which showed that great economic benefits could be derived from even a limited approach to the conjunctive use of ground and surface water — in particular, storing State Water Project water in Southern California ground water basins and retrieving it later during a dry period. With the present drought, this is exactly what is happening now. Over the long haul, such operations can delay or possibly even permanently reduce the need for additional surface facilities to conserve water.

The study also disclosed other facts:

- Water supplies beyond current demands are available in normal years for a few years;
- Conveyance capacity and power supplies are adequate to deliver large quantities of water to Southern California beyond those required for current needs;
- No insurmountable problems of water quality or of an environmental, legal, or institutional nature exist.

The study also identified the location and quantity of currently available ground water storage space in a number of ground water basins south of the Tehachapi Mountains.

Since that study was completed, the Department has mounted an energetic campaign to carry out conjunctive use on several fronts. Foremost among these is a project centered in the San Fernando Valley of Los Angeles County, which was selected as a prototype. We believe that as the problems we are meeting in that project are resolved, the principles that are established can be readily applied elsewhere.

The ground water basin in San Fernando Valley was selected largely because more is known about its geology and hydrology than perhaps any other basin in Southern California. It is equipped with the spreading basins, pipelines, well-fields, and other physical facilities needed for a successful ground water storage project. The Metropolitan Water District of Southern California (MWD) has completed construction of a tunnel to link the valley with the State Water Project.

Los Angeles County

Problems to be worked out range from agreement on methods for allocating costs; need for contract amendments; definition of what constitutes a water shortage; constraints of various sorts, such as City of Los Angeles charter provisions; and current unconcluded litigation.

Four cities — San Fernando, Burbank, Glendale, and Los Angeles — overlie the basin. Los Angeles City and County now operate the existing spreading grounds for spreading water from the Los Angeles Aqueduct or other imported water or storm runoff. The proposed storage project must be coordinated with current operations. All the cities are interested in retaining storage rights, and cooperative agreements safeguarding their interests are necessary.

The City of Los Angeles operates the basin now to prevent losses from overfilling and spilling. The city's close cooperation is vital to avoid losing water that could rise and flow down the Los Angeles River to the Pacific Ocean.

It was recognized early that agreements among the four cities, MWD, the Los Angeles County Flood Control District, and the Department of Water Resources will be absolutely vital to this enterprise. Consequently, committee members drawn from those agencies are working to agree on myriad points.

As the problems inherent in the ground water storage program have become more clearly defined and as each has been examined, the value of ground water storage has become clearer.

California's capability for storing ground water is enormous. In Southern California, as much as 13 600 cubic hectometres (11,000,000 acre-feet) of storage capacity is, or can be made, available. Even more space exists in the San Joaquin Valley. There, because of decades of falling water tables, 55 500 cubic hectometres (45,000,000 acre-feet) of storage is available. The Kern River Fan area and the White Wolf Basin, both in southern Kern County, and the Chino Basin in Riverside and San Bernardino Counties appear promising. Studies are also under way to determine how much ground water space exists in the Sacramento Valley.

As this work goes forward, much geohydrologic information needs to be developed, together with design of supplementary facilities for distribution, recharge, and recovery of ground water. Above all, the legal, institutional, and economic factors must be dealt with fairly.

The Department views conjunctive use of ground and surface water as a permanent program that must be integrated with State Water Project operations for truly efficient management.

Information for this article was contributed by Mitchell L. Gould, Operations Branch, Southern District Office, Los Angeles. (Mr. Gould is now retired.)

Kern County

Winter snow cover on the western slopes of the Sierra Nevada, as it appeared in 1974. This "blanket of water," the source of California's normal spring and summer snowmelt, adds greatly to streams, lakes, and reservoirs at lower elevations.

A Blanket of Water

SIERRA NEVADA SNOW: A VITAL SOURCE OF CALIFORNIA'S WATER

Much of California's water supply first takes shape as snow that envelopes its highest mountain ranges in winter, and then in spring, as the days become warmer, melts and flows down streams and into reservoirs. To make the best possible use of this vast resource, accurate and timely predictions of the amount of snowmelt that may be available are vitally important for a variety of wide-ranging purposes — for electric power generation, agriculture, and flood control, among others — all ultimately touching the life and well-being of every Californian, especially in a critically dry year, such as this one.

Water agencies need forecasts of snowmelt runoff to operate their reservoirs efficiently. Operators of hydroelectric power plants use the forecast information to plan releases of water from reservoirs to generate the greatest possible quantity of electric power and to match operation to periods of the highest demand for electricity. Irrigation districts use them in scheduling surface water deliveries to farmers and planning ground water pumping needs. Farmers key their planting to probable available water supplies, putting in crops requiring less water when forecasts indicate a drier season ahead.

Flows from melting snow are an extremely valuable source of water for irrigation in the San Joaquin Valley, a prime agricultural region. In fact, up to 75 percent of the valley's total yearly supply of water for croplands comes from the mountain snowpack.

Anticipating snowmelt flows is a critical factor in preventing spring floods in California. This is particularly true of the San Joaquin Valley, where major flooding has occurred when an exceptionally bountiful snowpack began melting during an early warm spell. When this happens, some of the damage is averted by capturing the streamflow in the many large reservoirs located in the foothills along the western slopes of the Sierra Nevada. Forewarned by projections of heavy snowmelt runoff, the operator of a reservoir can lower the water level early, keeping releases safely within the stream channel capacities, thus making room for the additional flow into the reservoir later.

The key to predicting how much water will run off from a river basin as the snow melts is to measure the water content of the snow. The basic field work is done by snow surveyors who travel into the mountains by helicopters, oversnow vehicles, skis, or snowshoes to collect the information that goes into making runoff forecasts. They carry with them tools specially devised for probing the snowpack. One is the sampling tube, a long hollow metal pole just under 5 centimetres (2 inches) in diameter that is driven through the snow to the ground. When the tube is withdrawn, a core of snow remains within the tube. The surveyors weigh the full tube and compare the results with the weight of the tube when empty. From this figure, plus the depth of the snow, they calculate the water content and density of the snow.

Snow surveyors take these measurements at sampling locations called snow courses, which are carefully selected sites — chiefly in mountain meadows where the snow is more likely to fall evenly without forming drifts. A network of about 320 of these sites covers California's major snow areas.

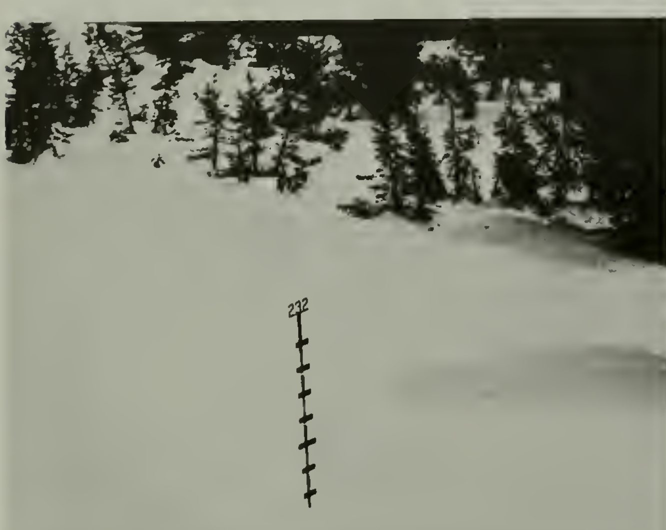
The field work is performed by more than 40 organizations actively involved in the California Cooperative Snow Surveys. These include a number of public agencies, some private companies, three public utilities, two large cities, several federal agencies, two State agencies, and the cooperative snow survey programs of Nevada and Oregon. One of the State agencies, the Department of Water Resources, coordinates this widespread field program. All measurements taken by the cooperating agencies are funneled into the Department of Water Resources' Snow Surveys Branch in Sacramento, where the data are assembled and forecasts of snowmelt flows expected in 22 major streams are prepared. Two groups of forecasts are made: one set is prepared for the irrigation season, April through July, and another set is prepared for the current water year, October through September.

How Snow Surveying Began in California

Few activities of the Department of Water Resources today have as long a history as snow surveys. The State of California first became involved in water supply forecasting back in 1917, when the Legislature authorized the (then) Department of Engineering to begin a program to survey snow conditions and prepare forecasts of snowmelt runoff. For several years, snowpack measurements of depth and water content were made in the watersheds of the Yuba,

Snowpack along a fork of the Yuba River in the Sierra Nevada melts and releases water in an early spring month of a pre-drought year.

Snow surveyors travel by ski through the high snow country to measure depth and water content of the snowpack. This man is carrying sections of a sampling tube in his pack



Aerial snow depth markers stand 6 metres (20 feet) high, their crossbars 6/10 metre (2 feet) apart. Surveyors calculate the depth of the snow by counting the number of crossbars showing above the snow and estimating the distance from the snow surface to the lowest visible crossbar. The marker at the left, located at an elevation of 2 220 metres (7,400 feet) in the southern Sierras, indicates the snowpack was 162 centimetres (64 inches) deep in April 1967. The right-hand marker shows a snow depth of 564 centimetres (222 inches) in June 1967 in the Owens River drainage basin. This unusual late-season pack resulted from May storms that year

Truckee, Carson, and Walker Rivers. Much of this field work was accomplished through agreements with three federal agencies — the Forest Service, the Weather Bureau, and the Bureau of Reclamation, plus some of the larger water users, thus laying the foundation of today's Cooperative Snow Surveys program.

In 1923, a lack of funds forced the State to pull out of the program for a time, but State equipment left in the field enabled other agencies to continue. By 1929, the State was able to reenter the program, which was then established as a statewide coordinated program with legislative appropriation to fund the issuance of forecasts. Agencies involved agreed to make the field surveys and furnish snow measurements to the forecasters in Sacramento — a practice that continues today. That same year, the small network of snow courses was expanded by 150 additional courses located throughout the Sierra Nevada. Shelter cabins to protect snow surveyors were built in remote areas, and the cooperation of a number of public utilities, irrigation districts, and municipalities interested in receiving water supply forecasts was enlisted.

The first practical application of snow data in forecasting snowmelt runoff occurred in 1910 at Lake Tahoe when Dr. James E. Church, a professor at the University of Nevada, successfully predicted how much the melting snow on surrounding mountains would cause the lake to rise. In those days (and now, as well), the lake level was controlled by a dam through which water was released to generate electricity. Pressed by demands from angered lakeshore property owners whose dwellings were flooded by the lake in years of high snowmelt runoff, the local power company sought the assistance of Dr. Church, an ardent outdoorsman who had been collecting snow data during hikes up nearby Mt. Rose since 1906. Comparison of his records with records of lake levels disclosed a good correlation between the water content of the snow

Survey team makes a calibration check at the site of an aerial snow depth marker to verify the accuracy of visual data obtained earlier from an aircraft flying over the scene.

Helicopters used to transport survey teams to snow courses at remote locations greatly speed up the collection of measurements.

Shelter cabin at Tyndall Creek in the upper Kern River drainage basin. Structures such as this are used by snow surveyors who work in isolated mountain areas, often for 10 days at a stretch.

Survey team loads its equipment on an over-snow vehicle in preparation for moving to the next measurement site.

on the mountain and the rise of the lake each spring. From this effort came a forecasting method that subsequently enabled the utility company to schedule releases from the lake to accommodate snowmelt runoff, and the lakeshore flooding decreased.

A few years later, California and several other western states — Nevada, Wyoming, Washington, Utah, and Oregon — recognized the great value of water supply forecasts to agriculture and electric power companies, and, from 1917 to 1928, established the many cooperative snow survey and runoff forecasting programs that are in existence in the western states today.

In California, snow surveys continue to be performed as they have for many years by teams of men who travel in winter through the mountains on skis and snowshoes. The tools they use — the Mt. Rose sampler and scale — remain largely as Dr. Church developed them in 1909.

Although Dr. Church's inventions are still the basic snow survey field instruments, other more sophisticated devices have been developed over the years that have greatly increased the fund of information that can be collected. In 1949, the use of aerial snow depth markers was introduced. The depth markings on those poles, which are tall enough to extend well above the deepest snowpack, are read from low-flying aircraft. One hundred fifty-eight aerial markers are in use in California today, supplying additional snow depth data for remote areas of the mountains.

In the 1950s, personnel of the U.S. Weather Bureau and the U.S. Corps of Engineers built the first automatic snow gage, which used a ground-level radioactive source and a Geiger-Mueller counting device mounted on a tower to measure the increase and decrease in snowfall. Attempts to operate this gage in the Kern River basin failed because its accuracy was open to question at maximum snow depths.

The Advent of Automation

Snow sensors, instruments that automatically "sense" changes in the water content of the snow, have been installed by the snow survey cooperators in snow areas of California to continuously record or transmit by radio the data used to prepare water supply forecasts. A network of 53 of these devices is presently in operation in several widely separated river basins. Fifteen sensors are connected to on-site recorders that are read periodically by snow survey teams during the winter, and 38 are linked by telemetry through the various cooperators to a central data collection point in the Department in Sacramento. Plans are to enlarge the network to about 124 sensors.

Often called snow pillows (because of the pillow-like appearance of the first ones developed), automatic snow sensors function in a basically simple manner. The sensing part of the instrument is made of a relatively flexible material — sheets of either heavy rubber or thin stainless steel — sealed on all sides. The sensor is installed in a level position just below the ground surface where, during a normal winter, it becomes buried beneath many feet of snow. Both the rubber pillow and the steel tank are filled with a liquid solution specially formulated so that it will not freeze, no matter how far the temperature drops. The weight of the water in the snow exerts pressure on the liquid, and the pressure changes as the water content of the snow changes after each new snowfall or as melting occurs. The readings register automatically on a nearby recording instrument or are sent by radio telemetry to Sacramento.

Although automatic snow sensors have proven invaluable in adding to the store of data on snow conditions, the Department and its cooperators in the California Cooperative Snow Surveys program have tested more than 35 variations in size, shape, and installation method in the field for many years, looking for ways to improve them. These studies have lead to an established installation standard: either a 12-foot-diameter rubber pillow or four 4-foot by 5-foot stainless steel tanks joined by piping. As the evaluations have continued, fresh experience has been gained that has improved the operation of these instruments and increased the accuracy of the data they provide.

The advantages of the automatic snow sensor are the timeliness and frequency with which information can be obtained. Forecasters are no longer restricted to making predictions based solely on monthly ground measurements. They can revise their forecasts as quickly as a situation warrants — weekly, daily, or even in response to a single storm. Any significant change in the weather, such as a rapidly developing storm or a sudden rise or drop in the temperature of the air, can alter conditions in the snowpack and create an urgent need for an updated runoff forecast. With automatic sensors tied to Sacramento, essential information is instantly available — to estimate rises in river levels and anticipate the possibility of flooding, for instance.

This forecast flexibility can be particularly important during and after storm periods, when knowledge of a changing runoff situation may allow a reservoir operator to alter the schedule of reservoir releases. This type of information can also be particularly useful during an extremely dry year, such as 1977, when rain and snow, snow accumulation, and runoff amounts were far below normal in the winter and spring. As the dry weather continued, reservoir releases have been cut to a minimum to conserve water to the greatest extent possible.

Automatic snow sensors, coupled with increasingly sophisticated telemetry and computer capabilities, have opened the door to an entirely new and wider means of surveying the snow and forecasting water supply conditions.

"The Eye in the Sky"

The newest tool available in forecasting snowmelt runoff makes use of some of today's most advanced technology — photographs of snow-covered areas (SCA) of the earth taken by satellites orbiting the earth. The Department is currently using satellite imagery of California's snow-covered areas to test whether this new technique improves the precision of its present forecasting capability.

Satellite images of the State are obtained from the LANDSAT 1 and 2 satellites of the National Aeronautics and Space Administration (NASA) and Satellites 2, 3, and 4 of the National Oceanic and Atmospheric Administration (NOAA). Both NASA and NOAA satellites maintain polar orbits around the earth. Each of the LANDSAT vehicles travels at an altitude of 910 kilometres (560 miles), photographing areas that measure 185 kilometres (115 miles) on every side. Each takes 18 days to cover the entire globe. This means a given point on earth is recorded once each 18 days. The images they provide of California's snow areas are sharp and clear.

Two additional NOAA satellites, the GOES 1 and 2, on the other hand, are "stationary" — that is, rather than moving about the earth, they travel with it, photographing one particular area repeatedly at

half-hour intervals. (GOES stands for Geostationary Operational Environmental Satellite.) They move at an altitude of about 40 000 kilometres (25,000 miles). Pictures that include California also take in the entire United States and part of the Pacific Ocean and the Gulf of Mexico in a single frame. Because of this great coverage, the detail of snow-covered areas in the Sierra Nevada is poorer than that obtained by the LANDSAT imagery, but it is still valuable because the frequency of these pictures provides some continuity on days when the LANDSAT photos are not available.

To apply the photographs of snow-covered areas to water supply forecasting, the satellite images have to be "reduced," or interpreted, in either of two manual processes. One involves laying a map of the features of a river basin directly over the LANDSAT photograph and tracing the boundary of the snow-covered area on the map. The other procedure involves an instrument called the zoom transfer scope. This device optically matches the image of the river basin map to the NASA or NOAA satellite image. The scope compensates for the distortion caused by the curvature of the earth because it can stretch the satellite image and change its shape and size to fit the configuration of the stream basin. Both processes provide square miles of snow cover, which are then converted to a percent of snow-covered area. From their knowledge of the terrain and other characteristics of a river basin, along with surface runoff records and data on the water content of the snow in the basin, forecasters can now include the extent of snow cover as another parameter in predicting possible runoff.

The Future of SCA

The use of areal snow coverage holds considerable promise as a means of measuring snowmelt runoff from April through July, the period in which the snowpack is usually melting and changing its boundaries. At this time, a definite relationship appears to exist between snow-covered area and the rate and volume of streamflow it produces.

The situation is reversed during the preceding five months, November through March, when the snowpack is accumulating. The snowpack is becoming deeper, but the extent of its boundaries are not changing appreciably, so satellite photos have limited value during this time as indicators of runoff.

An additional benefit of using SCA shows up when water content data from ground sensors and the SCA from the satellite images are combined. The result provides data which can now be used to accurately forecast the rate of runoff during the snowmelt period.

This has been demonstrated in two test areas that the Department of Water Resources has set up as part of a four-year contract with NASA. One test area is in Northern California, covering the Sacramento and Feather River drainage basins, and the other is in Southern California, covering the San Joaquin, Kings, Kaweah, Tule, and Kern River basins. Results to date have shown that improvements in forecasts are possible but that they vary from basin to basin, depending on the relative ruggedness of the terrain. In a region where every rise in elevation, say every 300 metres (1,000 feet), adds a nearly constant area of land, improvement has been slight. Such has been the case in the Kings River basin, where the various elevation zones are rather uniformly distributed. But where rises in elevation suddenly add much larger areas of land — as in the Kern River basin, which contains several large high-elevation meadows — the potential for forecast accuracy increases. That type of terrain responds readily to changes in snow-covered area.

The Department will continue to use these seven basins to study the effect of adding SCA to its water supply forecasting program.

Another Possibility for the Future

DWR is testing the application of satellites to relay of telemetered data from remote automatic snow sensors. The Department is conducting the investigation in cooperation with NASA.

If the program goes forward, information from snow sensors can be received by a satellite's data collection platforms and relayed to a data receiving station on earth. This will allow DWR to place its snow sensors in potentially useful sites in deep canyons and other rugged mountain terrain from which radio reception is presently impossible. This will make more effective snow data collection possible and also eliminate the need for costly mountain-top radio repeater stations.

DWR has one data collection platform in operation at present that is using the GOES satellite. It monitors snow water content and the temperature of the air in a mountainous region of El Dorado County. Several more are planned for other areas of the State, as well as a data receiving station in Sacramento to be shared by DWR and the State Division of Forestry.

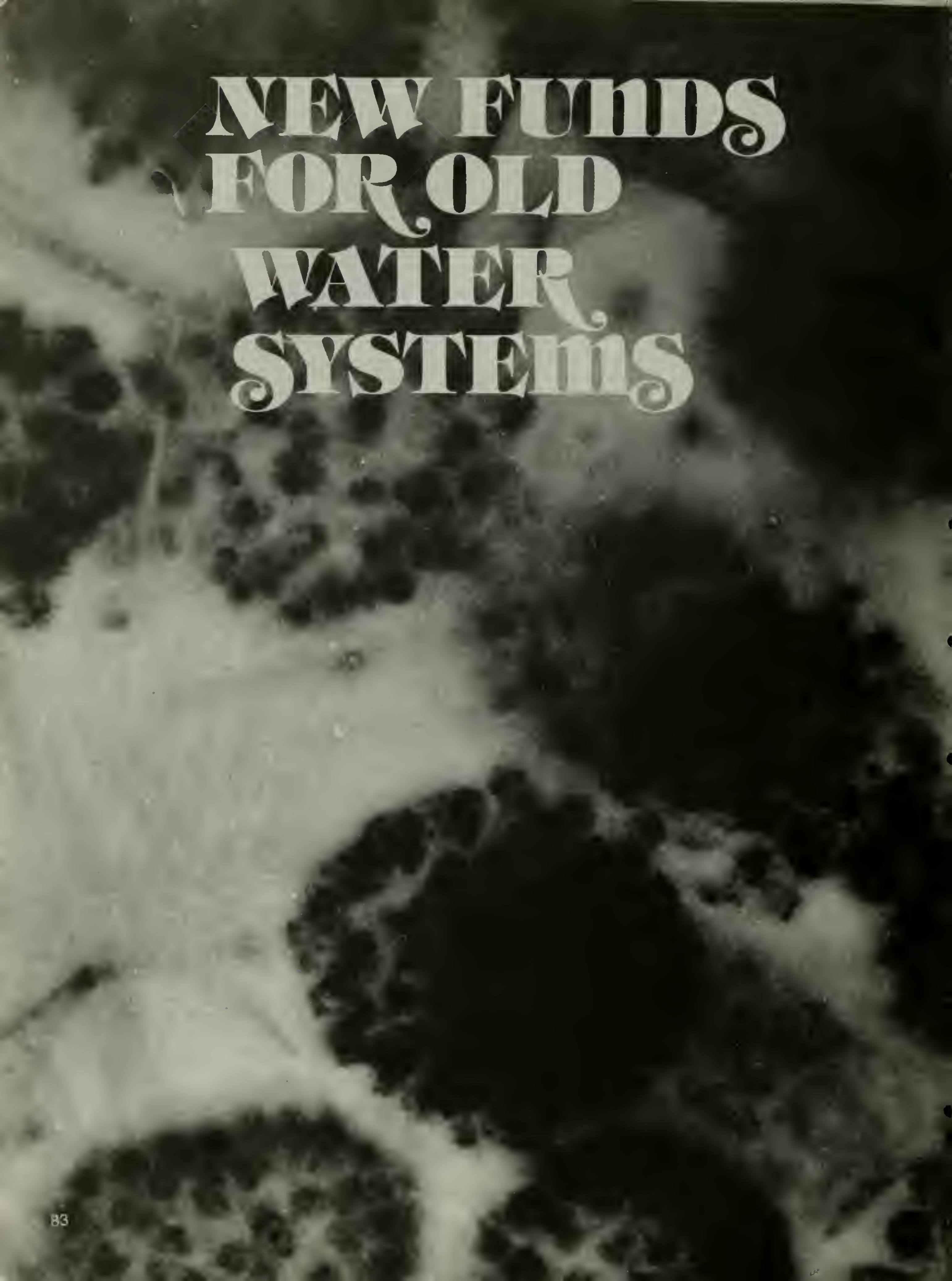
Results of these tests may make a big difference in snow surveys and water supply forecasting in the near future.

View of the entire Sierra Nevada, as seen by a NOAA Satellite 3 on April 28, 1975, showing the extent of snow coverage. The central Pacific coastline is visible at the lower left and the state of Nevada at the upper right. The boundaries of drainage basins whose snowpack provides the basis for forecasting a major part of California's annual water supply have been superimposed on the satellite photograph. In subsequent photos, the snow-covered areas were shown to be gradually shrinking as spring melt-off continued.

Information for this article was contributed by A. Jean Brown, Chief; Charles H. Howard, Associate Engineer, Water Resources; and Ned. R. Peterson, Assistant Engineer, Water Resources; all of the Snow Surveys Branch, Sacramento.

Water supply forecasts based on snow surveys are published by DWR annually in February, March, April and May in the Bulletin No. 120 series, "Water Conditions in California" (four reports; free). Additional data appear in a new yearly publication, Bulletin No. 202, "Water Conditions and Flood Events in California". The most recent issue is Bulletin No. 202-76 (July 1977), covering the period October 1975 through September 1976. This report is also free of charge.

NEW FUNDS FOR OLD WATER SYSTEMS



Half of California's 22 million residents are drinking tap water that is either chemically unsafe, just plain dirty, or bacteriologically contaminated. A 1974 report issued by the State Department of Health explains that, while only a relatively small percentage of State residents consume water that fails to meet established bacteriological standards, more than 13 million Californians drink tap water whose purity is objectionable in some way.

Responsibility for this alarming situation lies squarely with the State's domestic water retailers. Yet these suppliers often cannot secure financing for the improvements to their water systems that would bring the quality of their water up to the public health standards.

One possible solution to this dilemma is the Safe Drinking Water Bond Law of 1976, approved by California voters in the June 1976 primary election. This law offers water agencies financial assistance in the form of $175 million in bond money to upgrade their domestic water systems. The program is jointly administered by the Department of Health and the Department of Water Resources. In the language of the Bond Law, the funds should promote the flow of "pure, wholesome, and potable" water "that does not endanger the health or lives of human beings." Loans as high as $1.5 million are available to eligible water suppliers. Public agencies are eligible for the loans and will be able to obtain grants up to $400,000, if the Legislature chooses to authorize grants at a later date.

Water agencies need money for a variety of projects, ranging from the construction of new storage and distribution facilities to the renovation of existing filtration and treatment plants. The Department of Health ranks all requests according to health needs and reviews construction plans before issuing or amending water permits. It is DWR's task to determine which receive financial aid, and how much money they need to complete the projects. DWR also makes loan agreements with the agencies — acting as the Bond Program's loan officer.

Water suppliers that borrow money through the program pay low interest rates on the loans, which cover all costs of the project. That includes administrative costs, which may not exceed three percent of the loan amount. Although the maximum allowable loan repayment period is 50 years, in most cases repayment is over a 35-year period or less.

On September 15, 1976, DWR mailed 1,200 sets of rules, application forms, and filing instructions to all water suppliers throughout the State. By the end of November, 82 suppliers returned completed application forms, requesting loans that totalled over $88 million. (About half these early applicants were public agencies. The rest were private or mutual water organizations.) About the same time, the Department of Health established an interim priority list of 82 applicants. Today, that list names 175 applicants, and 25 have either received loan commitments or been found ineligible for financial assistance under the program.

Usually, an applying agency is denied bond money only if it has other sources of funding, or if it fails to demonstrate it has the means to repay the loan. All those receiving financial aid *must* agree to adopt water-saving measures.

By the end of June 1977, water agencies had received $3.5 million worth of loan commitments from the State. In the current fiscal year, DWR expects to approve applications for an additional $30 million in loans.

Information for this article was contributed by Donald Engdahl, Associate Governmental Program Analyst, Water Conservation and Supply Branch, Sacramento.

California's standards for safe drinking water are based on the following tests: *Bacteriological Safety.* Laboratory technicians test drinking water for the presence of *Escherichia coli*, a bacterium found in the human intestine and fecal matter. The water is considered unsafe for human consumption if it contains more than four *E. coli* bacteria per 100 millilitres of water. *Chemical Safety.* Drinking water is also tested for harmful chemicals, including arsenic, chlorides, copper, nitrates, and sulfur. If the sample contains too many particles of any one of these substances, it is considered chemically unsafe. *Esthetics.* Finally, drinking water is given a subjective test to determine whether it appears, smells, or tastes objectionable.

Vanishing Vegetation

The Face of the Sacramento River is Changing... Rapidly

With its large flows of high quality water and its miles of lush streamside plant growth, the Sacramento River is a singularly attractive and valuable natural resource that is, not too surprisingly, under pressure from differing and sometimes conflicting interests. Farmers in increasing numbers are clearing the land to plant crops on the rich soils along its banks. Environmentalists are seeking to retain the native trees, shrubs, and grasses, the large sand and gravel bars, the sweeping meanders, and the river's overall primal appearance in a natural state.

The 144-kilometre (90-mile) stretch of the river from the City of Sacramento upstream to the town of Colusa is relatively narrow, with high levees on each side closely following the river's course. The levees lie about one-half kilometre (about one-quarter mile) apart. The lands outside the levees are intensively developed for agriculture, and any land within the levees is cleared to permit the high, fast-running winter flows to pass freely. Only a little native vegetation remains.

However, from Colusa north to the community of Ord Ferry, the setting changes dramatically. In these 64 kilometres (40 miles) of river, levees are seldom parallel and are often set back from the twisting course of the river 1½ kilometres (1 mile) or more. The water channel is low and occupies only a small part of the land lying between the levees. Although much of the land from riverbank to levee is situated within the floodway, it is still high enough to escape being flooded by all but the highest flood flows. The remaining 192 kilometres (120 miles) of the river extending north from Ord Ferry to Keswick Dam in Shasta County have no levees, for the most part. Before its

Many oxbow lakes remain along the Sacramento River north of Sacramento, visible reminders of the paths the river has taken in its meanderings.

lands were settled, the Sacramento Valley contained vast wilderness areas with a wide variety of native environments for wildlife. The most productive of these habitats were the dense, tangled stands of vegetation that grew along the banks of streams.

Over the past 100 years, however, profound change has taken place; large acreages of the valley's wild areas have been cleared for farming and urban settlement. Only certain stretches of the Sacramento river still possess their original wild beauty. Most of the native plant life remaining along the river grows between Keswick Dam and Ord Ferry, and some also remains in the section south to Colusa. But as each year passes, more and more of the higher riverbank lands that generally escape flooding are being cleared for agriculture.

The wildlands areas that are still present support a wealth of wildlife, but their increasing scarcity has greatly enhanced their value as wildlife habitat. The number and variety of birds and animals that can live in an area depend on how much dense cover is offered by uncleared land and whether grain and forage are available in nearby farmlands. Clean-tilled and heavily sprayed orchards offer no means of survival.

In recent years, the change taking place along the Sacramento River has been visible to any observer, but not until the Department of Water Resources surveyed the situation in the early 1970s was the real extent of the change known. A study of a 262-kilometre (164-mile) stretch of the river from Keswick Dam to a point near Colusa disclosed that more than half the native vegetation growing above flood level in 1952 had vanished by 1972, to be replaced chiefly by orchard plantings. In just 20 years, 6 665 hectares (16,470 acres) of natural growth had been reduced to 3 161 hectares (7,810 acres) — an average yearly loss of 175 hectares (433 acres). At that rate, if nothing halts it, this section of the river could be stripped of all native trees, shrubs, and grasses by 1992, thus erasing the habitat of a large population of wildlife, including an estimated 1,700,000 birds representing 82 species. When a wildlife environment is lost in this manner, its inhabitants are generally lost too. The displaced birds and animals may move to adjacent lands in search of food and cover, but the neighboring habitat is often filled to capacity by other wildlife and is unable to support the newcomers as well. Large numbers of wild creatures simply do not survive.

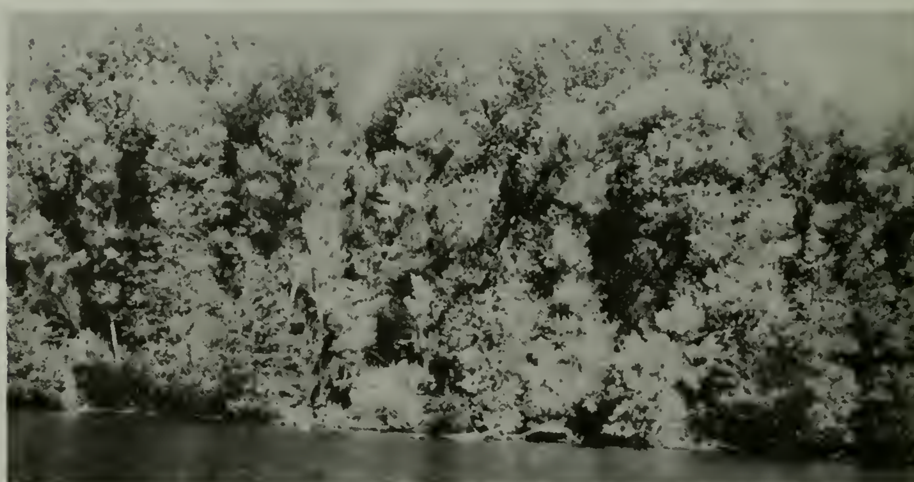
The study, which covered a total of 29 500 hectares (72,860 acres), also disclosed that:

- Orchard lands increased 415 percent, from 1 279 to 6 592 hectares (from 3,160 to 16,290 acres). The greatest change occurred in southern Tehama County.
- 174 hectares (430 acres) of natural growth were cleared from low-lying riverbank lands that are flooded nearly every winter.
- Urban lands increased by 740 hectares (1,830 acres).
- 2 173 hectares (5,370 acres) of croplands (out of a total of 9 900 hectares, or 24,500 acres) were converted to orchards.
- Gravel bars and oxbow lakes decreased by nearly 400 hectares (1,000 acres), and river surface had increased slightly more than 80 hectares (200 acres). (An oxbow lake is created when a river changes course, isolating part of it from the main channel.)

Changes in the use of riverbank lands were obtained for the study by comparing low-level aerial photographs taken in 1952 and again in 1972. Lands mapped for the study included farmlands (grain, row crops, and orchards), native vegetation (trees, shrubs, and grasses), marinas, homes, and parks. The height of the land above flood level was an important factor. Flood control levees were the primary mapping limit.

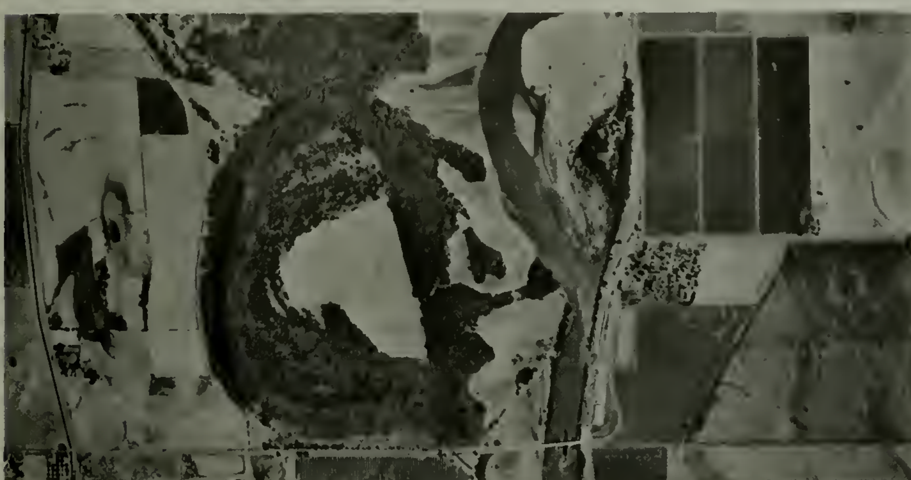
The Sacramento River is an old river, geologically speaking, and it has a tendency typical of such features — it wanders across the floodplain, changing course from time to time. There is evidence the

Gravel bar beginning the slow process of soil formation and growth of early vegetation.



Typical stands of dense streamside vegetation along the river's edge.

Low-lying riverbank lands that are subject to frequent winter flooding.



The Sacramento River at Butte City, Glenn County, in 1952. Heavy stands of trees and other vegetation appear through center left of this view, and the river takes only a moderate bend just north of the town.

The Sacramento River at Butte City in 1972. Trees have now been replaced by orchards and the river's course just north of the town has changed dramatically.

river has altered its course as much as several miles in some places at some time in its history. Since 1952, some stretches have meandered more than a half mile. In fact, many points of interest that appeared on one side of the river in 1952 showed up on the other side in 1972. In many sites, the riverbanks had been severely eroded. Mapping was therefore often greatly complicated by these events.

In the past three years, new threats to the river's environment developed. The price of wood chips rose to a very favorable level, and many acres of riverbank property have been rapidly cleared of sycamore, cottonwood, alder, and oak trees. Land owners have been defraying clearing costs by selling the trees for wood pulp. The demand for quality firewood has also brought woodcutters into the area to cut and haul oakwood from a number of sites along the river.

What's Being Done for the River?

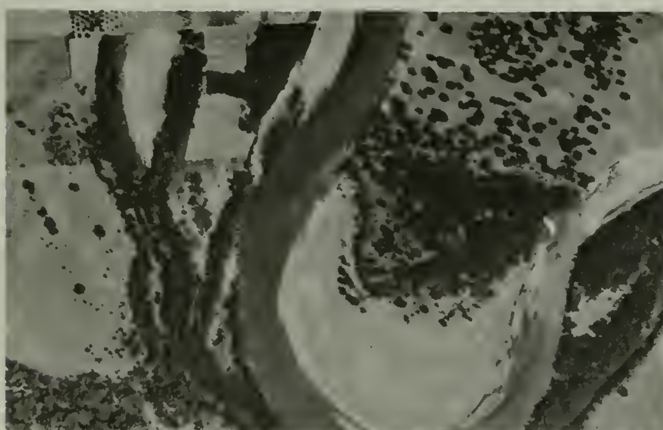
If some of the valuable native plant life still growing along the river is to be preserved, the individuals, organizations, and government agencies that are concerned about the river's future must come to agreement on how this will be achieved. A positive step in this direction came in 1975 when the Upper Sacramento River Task Force was created to bring together interested persons and groups. These included the State Departments of Navigation and Ocean Development, Fish and Game, and Water Resources; The State Reclamation Board; the State Water Resources Control Board; the Sacramento Valley Land Owners Association; the U.S. Corps of Engineers; the U.S. Bureau of Reclamation; the U.S. Fish and Wildlife Service; the U.S. Bureau of Land Management; and the boards of supervisors of Shasta, Tehama, Colusa, Glenn, and Butte Counties.

The task force is preparing an environmental atlas of the Sacramento River that will show salmon spawning areas, rare or endangered wildlife habitats, prime areas of native growth, areas of severe bank erosion, navigation hazards, public lands and access routes, rock bank protection sites, agricultural uses, private and public recreation areas, and oxbow lakes. The atlas will be invaluable in planning future land uses of all types along the river.

At the time the task force came into being, several organizations were already involved in trying to save the river environ-

The Sacramento River north of Princeton, Colusa County, in 1952.

The river north of Princeton in 1972, showing severe erosion of orchard lands. About 34 hectares (85 acres) of agricultural land has been lost over the years as the river cut deeply south.



The Sacramento River south of Woodson Bridge, Tehama County, in 1952

The river south of Woodson Bridge in 1972. Orchards at the top of this view have displaced thick stands of native trees. New gravel bars are also forming in the river.

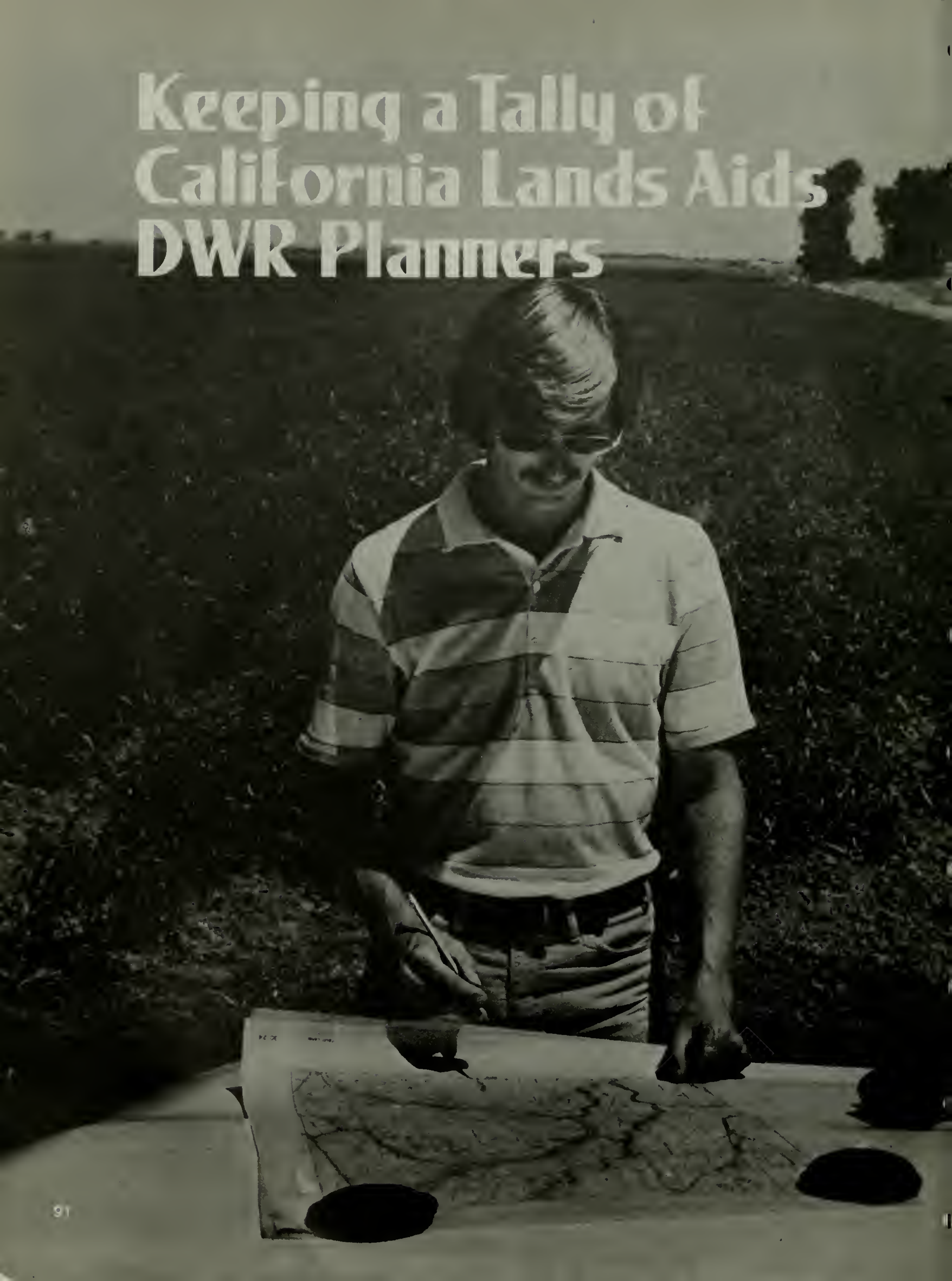
ment. The State Department of Parks and Recreation was at work developing a plan to purchase selected parcels of land between Redding and Colusa as part of a river rafting and primitive camping system. The National Audubon Society has also demonstrated its concern by working with the Wildlife Conservation Board to purchase a large number of undeveloped parcels along the river to protect wildlife. The Bureau of Land Management is exchanging land elsewhere for parcels on the river that will provide public access. The Corps of Engineers has a continuing program to control bank erosion by placing rock bank protection. The Sacramento Valley Land Owners Association, comprised mainly of farmers, is also interested in protecting the river's banks and in controlling bank seepage along the river. The Department of Water Resources monitors these activities as part of its statutory responsibility to watch over all water resources of California. Another development has taken place that will also greatly benefit the Sacramento River, this time between Chico Landing and Red Bluff. The Department of Water Resources, working with the Department of Fish and Game and The State Reclamation Board, has obtained agreement from the U.S. Corps of Engineers to alter its riverbank construction practices in ways that will be more favorable to the river's environment. Examples of the type of work the Corps has agreed to include placing riprap (rock protection) at some sites along the river only as high as necessary to prevent damage by river flows (rather than covering the banks completely), allowing the regrowth of natural vegetation, and preserving trees growing at the river's edge, wherever possible. At sites where native trees, shrubs, and grasses are growing to the river, the Corps will provide a 45-metre (150-foot) conservation easement. This means the natural plant life in these areas will remain forever protected. The Corps will time its work so that it does not interfere with fish moving upstream to spawn.

This year marked the beginning of a second DWR land use study of the Sacramento River to document changes that have taken place since 1972. Although the results will not be known until some time in 1978, this follow-up investigation is fully expected to confirm what has been observed up and down this northern part of the river in the past few months: uniquely valuable stands of native trees, grasses, and shrubs are continuing to vanish at an alarming rate.

Information for this article was contributed by Robert R. McGill, Chief, Land and Water Use Section, Northern District Office, Red Bluff.


SHASTA
LAKE
S H A S T A
KESWICK
DAM
Redding
T E H A M A
Red
Bluff
Chico
B U T T E
ORD FERRY
CHICO LANDING
G L E N N
Willows
Butte
City
Princeton
Colusa
L A K E
C O L U S A

Keeping a Tally of California Lands Aids DWR Planners



As with many functions of the Department of Water Resources, the task of inventorying the use of land in California is work that continues year in and year out, whether rain and snow are plentiful, or whether, as happens now, we are in a drought period. As the State agency responsible for statewide water planning, DWR needs to know how the State's lands are being used and what directions development is taking. This information is fundamental in determining present water needs and anticipating those of the future.

Land use surveys are a means of measuring and recording whatever natural or manmade features occupy specific areas on specific dates; taken at regular intervals over the years, they provide an invaluable record of change or, as is sometimes the case, lack of change. They provide the basis for determining not only the quantity of water used, but also the characteristics of water use, information required for water quality studies, for identification of opportunities to conserve water, and for other DWR studies.

Consider these facts: as one of the world's greatest growers of food and fiber products, California is faced with ever increasing demands for its agricultural output, and California's population has doubled in the past 25 years and is forecast to double again in the next 45. The picture that forms is clear: our need for water will only become greater as time passes.

If we are to match supply with demand, prudent management of our water is essential, even with normal rainfall. With the present drought, of course, our difficulties are multiplied enormously. Planning is a big part of the answer. In water management, this means having water when and where you need it, both now and later.

Land use surveys have been a major contributor to the planning efforts of the Department of Water Resources for 30 years. The survey furnishes an inventory of the uses of land by types (agricultural, urban, recreational, and native vegetation), by location, and by size. DWR uses this information to estimate past and present water use, to determine the nature, size, and location of land use trends, and to predict future land use as a basis for estimating future water use.

Agricultural use of water is probably the single most important factor in the overall picture because crop irrigation presently accounts for 85 percent of all water used in California. Determining how much water any particular agricultural area is using and will be using in the near future is important in ordinary times. As the second year of California's severest drought closed, this information was critically needed. Water use by crops is based on known amounts applied to bring them to full production. Corn, for example, takes about 0.6 metre (2 feet) of water per crop. Field beans use about the same amount or slightly less. However, alfalfa needs twice the water corn does, and rice, three to four times as much. Climatic differences, which are typical of California, cause wide variations. Crops grown in coastal areas where summers are relatively cool need less water than crops grown in the Central Valley's high-temperature summers.

The objective of DWR's land use surveys program is to maintain a file of near-current land use data for all of California. Surveys are generally made once every six to eight years in urban areas and irrigated farmlands and about every 10 to 15 years in upland and mountainous regions. However, at times it becomes necessary to deviate from the long-range schedule to meet special data needs. The Sacramento Valley Water Use Survey, conducted in 1976, is a good example. This far-reaching investigation was undertaken for two reasons. One was to find out how a year of abnormally dry weather was affecting the lands of the Sacramento Valley and the Sacramento-San Joaquin Delta. The other purpose was to collect field data needed to manage water supplies in these regions in the most effective way, should the drought continue.

Land use surveyors assisted the overall survey by photographing and mapping all of Sacramento Valley from Redding to the Delta, plus the Delta islands and waterways, a total area of about 1 675 000 hectares (nearly 4,140,000 acres). They surveyed areas of streamside vegetation, surface water, and a variety of other non-farming uses.

The big question was: Why was considerably less Sacramento River water reaching the Delta than expected, despite large amounts of water released from Shasta Reservoir to combat the inflow of salt water into the Delta? Obviously, the water was going somewhere, but where? One significant finding was that farmers were having to irrigate far more heavily than usual to make up for the dramatic drop in rainfall. They were drawing more water than in wet years directly from the river and were also pumping more water from wells, which caused underground water to seep from the riverbed into the basins that supplied the wells.

Another reason the river was lower was that farmers were combatting the drought by making better use of water. In a normal year in the Sacramento Valley, about 30 percent of the water taken from the river for irrigation drains back to it. In 1976, however, farmers were allowing only about five percent of this water (called return flow) to escape their control. The remaining 25 percent or so was being circulated back to the land.

Regularly-scheduled land use surveys provide the information needed to estimate amounts of water being pumped from underground basins, a factor of critical importance in this water-short period. One way estimates of these amounts are determined is to subtract the total amount of surface water from the total irrigation water applied. The difference is the total amount of water being drawn from wells for irrigation. (Total applied water is estimated by multiplying the number of irrigated acres by the average amount of water per acre a particular crop is given to grow it to maturity.)

Survey data are used to record conditions in upstream areas where rivers and streams begin so that changes affecting the quantity of flow to downstream users can be kept track of. The surveys also inventory wildlife habitats, give a basis for finding out what is happening to California's prime agricultural lands, and map the limits of resources in the natural environment.

When land owners in an area propose the formation of a water storage district or an irrigation district, DWR's land use surveyors again enter the scene because DWR is required by law to make certain investigations into the feasibility of such action. This calls for surveys to determine what lands are available for various purposes, the extent to which present water supplies are being used, and whether there is economic justification for development.

Because DWR's land use surveys are the only source of maps that provide a picture of land use for the whole State on a continuing basis, DWR receives many requests for material from other public agencies and from the private sector as well. These organizations apply the data in a variety of

When crop identification from slides is uncertain, land use surveyors make field checks at the site to ensure the accuracy of their mapping.

ways, ranging from estimating water requirements for crops (much as DWR does) to studying the effects of different levels of noise on residential development around airports. For example, natural resources agencies have used survey results to study the decreasing habitat of rare and endangered wildlife; public and private power companies have often used them in siting power plants and routing transmission lines; and agricultural agencies use these data in statistical reporting and in controlling the spread of crop diseases. Other applications include environmental impact reports, legislation to control land use, industrial plant site selection, and studies of the economic impact of proposed agricultural regulations.

Other agencies also conduct their own surveys and develop land use information. These include the U.S. Bureau of Reclamation, the State Department of Agriculture, county agricultural and planning departments, and irrigation districts. These organizations often have entirely different purposes for surveying, but, wherever possible, DWR adds the information to the findings of its own surveys. Unfortunately, most of the time this material is not suitable for the Department. It often lacks the essential land use categories; it may not cover the complete hydrologic or geographic areas being studied; or it may simply lack the level of accuracy required by the Department.

Space age technology is contributing to the survey of land uses in California through the use of the earth-circling Land Resources Satellite (LANDSAT). Imagery obtained from the LANDSAT may well play an important part in DWR's future land use investigations. For a number of years, various researchers from both the academic and the private sector have been looking into the usefulness of satellite photography in the study of California's earth resources. DWR has assisted the University of California in a number of studies funded by the National Aeronautics and Space Administration. It has furnished maps and tabulations for comparison with similar mapping based on satellite imagery, and it has directly participated in certain phases of the studies.

Judging by the results of the research work to date, LANDSAT seems to offer an excit-

Land use categories cover all possible uses that can occupy the lands of California The partial list below serves only to indicate the broad range of information the Department of Water Resources collects.

Agriculture

Subtropical Fruits
Grapefruit, Dates
Oranges, Avocados
Lemons, Olives

Deciduous Fruits and Nuts
Apples, Cherries, Figs
Pears, Peaches, Walnuts
Plums, Prunes, Almonds

Grain and Hay Crops
Barley
Wheat
Oats

Field Crops
Cotton, Safflower
Hops, Sugar beets
Corn, Flax

Truck and Berry Crops
Artichokes, Lettuce
Asparagus, Onions
Carrots, Potatoes
Celery, Tomatoes
Flowers, Strawberries

Pasture
Alfalfa
Clover

Vineyards

Rice

Idle Land

Other Uses
Farmsteads
Feed lots
Dairies
Abandoned orchards and vineyards
Partially irrigated crops

Urban

Commercial
Offices and stores
Hotels and motels
Apartments
Hospitals and prisons
Schools
Auditoriums, theaters, churches, parks, arenas

Industrial
Manufacturing plants
Oil fields, quarries, public dumps
Warehouses, railroad yards, tank farms
Oil refineries
Paper and saw mills
Canneries
Meat packing plants

Vacant lands
Paved areas
Unpaved areas

Residential
One- and two-family units
Mobile home parks

Recreation

Summer home tracts
Motels, hotels, resorts
Camp and trailer sites
Parks

Vegetation

Native vegetation
Swamps and marshes
Meadowlands
Water surfaces

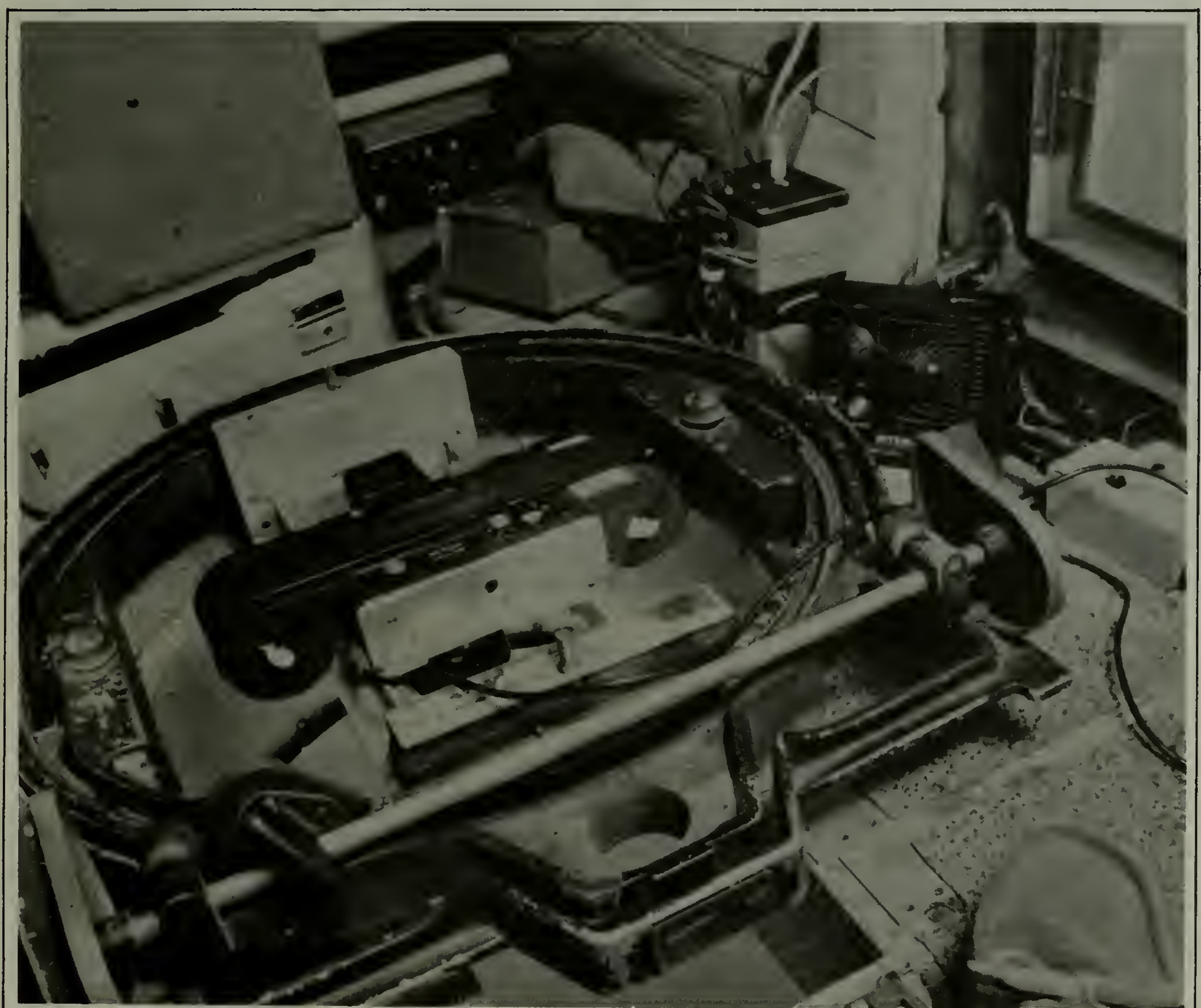
ing potential for land use surveying, although its application will probably be somewhat limited until considerably more research is done to develop techniques for identifying individual crops. For that reason, conventional photography can be expected to continue as the mainstay of the survey program in the near future. LANDSAT images may be useful in assessing multiple cropping and winter cropping patterns more effectively than has been possible in the past. While DWR flies over a particular area only once every few years, a LANDSAT vehicle passes over California at nine-day intervals through the year (with two satellites in operation).

Since 1947, when the State Legislature asked for an investigation of the water resources and present and future needs of all river basins in California, DWR and its predecessor agencies have been compiling land use statistics on all parts of the State. At the time these surveys began, the underlying idea was to collect information for a comprehensive water development plan for the State (later to be published as the California Water Plan and culminating in the State Water Project). This first body of data came from such sources as federal agencies, irrigation districts, and county agricultural offices.

Another early investigation, this time conducted between 1954 and 1956, involved a detailed examination of 15 counties lying north of the City of Sacramento and east of the Coast Range (Bulletin No. 58, "Northeastern Counties Investigation", DWR, June 1960). Then in 1957, DWR launched a seven-year study to determine amounts of water originating in major watersheds and amounts available for export to other regions of the State. The results were combined with land survey data and appeared in a group of reports on land and water use (the DWR Bulletin No. 94 series) that have been a vital part of departmental planning.

A detailed survey in 1958 of most of the floor of the San Joaquin Valley was a particularly significant achievement for the surveys program. This was the first time DWR surveyed such a large, highly developed agricultural area within a single year.

In 1966, DWR embarked on its regular survey schedule that continues to the present,



The 35-millimetre electric-drive Nikon aerial camera used in making aerial surveys of land use is shown mounted on the floor of the plane. It shoots a picture every 15 seconds while the aircraft is flown at an altitude of aobut 1 500 metres (5,000 feet) at about 280 kilometres per hour (130 miles per hour).

Colored photoslides taken during aerial surveys are projected on a screen, and the types of crops they show are interpreted by survey personnel who code the information on maps especially in the more intensively settled parts of each county.

In the earlier days of land use investigations, DWR's surveyors traveled by car to areas under study to identify every crop, to locate boundaries of fields, and to make other on-site determinations. They had to rely on black and white photographs, which were often rather old, to help locate field boundaries. Their findings, as delineated on the photographs, were then transferred in the office to U.S. Geological Survey base maps, a time-consuming procedure. Field inspection has remained the most basic aspect of the mapping process, notably in agricultural areas, although it is now more often used to check the accuracy of interpretations of aerial photos, rather than as a primary source of data.

The use of up-to-date color aerial photography has greatly increased the efficiency of the mapping process because it provides the mapper the opportunity to identify many features through photo interpretation. Such features as the boundaries of crops, the limits of urban spread, and trees, vines, and various other crops can be readily distinguished. Working from a color photo, an experienced mapper can easily differentiate among the shades of green exhibited by fields of tomatoes, corn, and alfalfa, for example.

DWR first worked with aerial photos obtained from other agencies and later with photos adjusted to the size and scale of quadrangle maps from the U.S. Geological Survey. By 1967, DWR was taking its own aerial shots, producing 35-millimetre color slides. Flights are made every summer over some part of the State, during a period of three to four weeks. The plane travels at about 1 500-metre (5,000-foot) elevation along north-south lines about 1.6 kilometre (1 mile) apart in developed areas and along such features as roads and streams in the more sparsely settled areas.

After the slides have been studied and interpreted, and the categories of land use have been mapped and field-checked, the numbers of acres in each category are calculated. These statistics are tabulated by quadrangles, by counties, and by hydrographic units, and by special study areas, such as proposed water service areas, areas served by individual diversions of surface water, alluvial fill (valley floor) areas, ground water basins, drainage problem areas, elevation zones, incorporated cities, and census tracts. This information can be called up in varying arrays.

This year DWR has made a special survey of the Delta at the request of the DWR Delta Studies Group, the U.S. Bureau of Reclamation, and the State Water Resources Control Board. The object has been to determine whether the drought-lowered Sacramento River flows have influenced the pattern in which crops are planted. For instance, are farmers switching to crops that need less water? If so, how many acres and what types of crops are involved? Another question is: Are farmers following the practice of double-cropping to the same extent as in other years? Planting two crops per field per year usually takes a third to a half more water than planting only once.

As the drought has worsened in California, the Sacramento River has, because of low flow, been less and less able to hold the quality of water in the Delta at desirable levels and prevent the Pacific Ocean from infiltrating its waterways. Aerial photographs taken during the survey will be examined for signs that the poorer quality water flowing among the Delta islands has altered cropping patterns and other agricultural activity.

The scope of land use information compiled by DWR between 1950 and 1970 has been published in Bulletin No. 176, "Land Use in California," which is an index to land use surveys conducted by DWR during those 20 years. The report was issued in December 1971; it is free of charge.

Information for this article was contributed by Frederick E. Stumpf, Chief, Water Utilization Section, San Joaquin District Office, Fresno.

DWR planners apply the information gained from land use surveys to a wide range of purposes:

To estimate amounts and locations of irrigation water farmers will use and their ability to pay for that water. (The factor of payment becomes important to DWR where water is being purchased under contract with the State Water Project.)

To detect and identify developing shortages of water and determine what other supplies are available for use locally or for routing to other areas.

To determine the nature and quantity of water use by cities, farms, and industry — including the times it is used and where it is routed — so that the State and federal reservoirs supplying them can be operated at the highest levels of efficiency. (This type of study goes on constantly because amounts of water used and types of uses are fluctuating all the time.)

To find how more efficient irrigation practices can lead to greater water savings.

To determine where and how the use of agricultural herbicides, pesticides, and fertilizers are impairing water supplies.

To evaluate water rights.

To assess flood damage and study flood plain zoning.

To find areas that will benefit from the use of reclaimed water.

To identify locations of current or possible future soil drainage difficulties.

To study the effects of changes in water quality on specific agricultural areas.

ACKNOWLEDGEMENTS FOR PHOTOGRAPHS

California Department of Fish and Game, Yountville
Bob Gill, page 38
Jack White, page 38

California Department of Fish and Game, Redding, pages 85-86, 87

U.S. Army Corps of Engineers, Sacramento District, Public Affairs Office, pages 45-46, 50, 51, 56, 58, 59-60

University of California, Cooperative Extension Office, Davis, pages 1, 5, 6, 7 (William E. Wildman, pilot, and Jack K. Clark, photographer)

Arlene Hetherington, Chico, page 12

City of Los Angeles, Department of Water and Power, Photographic Section, pages 67-68

Doug Powell, pages 77-78

National Oceanic and Atmospheric Administration, page 82

U.S. Soil Conservation Service, page 89

California Department of Water Resources, pages 3, 4, 11, 12, 53, 54, 55, 57, 62, 77, 78, 80
Division of Design and Construction, Sacramento, pages 31, 32, 33
Division of Operations and Maintenance, Sacramento, page 34
Northern District Office, Red Bluff, pages 41, 42, 87, 88, 89
Division of Safety of Dams, Sacramento, pages 63, 64, 66
Melinda Merritt, page 12; Jim Wardlow, pages 91, 95; Paul Weber, page 94 (all Sacramento)

State of California
Department of Water Resources
CALIFORNIA WATER COMMISSION

MICHAEL GLAZER, Chairman, Los Angeles

Thomas K. Beard	Stockton
Alexandra Fairless	Arcata
Scott E. Franklin	Newhall
Daniel S. Frost	Redding
Merrill R. Goodall	Claremont
Ralph E. Graham	San Diego
Enid Pearson	Palo Alto

Orville L. Abbott
Executive Officer and Chief Engineer

Tom Y. Fujimoto
Assistant Executive Officer

The California Water Commission serves as a policy advisory body to the Director of Water Resources on all California water resources matters. The nine-member citizen Commission provides a water resources forum for the people of the State, acts as liaison between the legislative and executive branches of State Government, and coordinates federal, State, and local water resources efforts.

Published by
State of California
The Resources Agency
Department of Water Resources
at Sacramento, California
in the
Division of Planning
Donald E. Owen, Division Chief
Under the Direction of
Environmental Measurement Branch
Kenneth L. Woodward, Chief
Water Resources Evaluation Section
Robert L. McDonell, Chief
Edited by
Travis Latham, Research Writer

RONALD B. ROBIE
Director
Department of Water Resources

ROBIN R. REYNOLDS
Deputy Director

GERALD H. MERAL
Deputy Director

ROBERT W. JAMES
Deputy Director

CHARLES R. SHOEMAKER
Assistant Director

Copies of CALIFORNIA WATER are available at no charge from:

State of California
Department of Water Resources
P.O. Box 388
Sacramento, California 95802

Publications of the Department of Water Resources referred to in CALIFORNIA WATER may be obtained by writing to:
State of California
Department of Water Resources
P.O. Box 388
Sacramento, California 95802
Availability will depend on stock on hand. If DWR cannot supply you, please check with your public library. All DWR reports identified with a bulletin number, as well as some others, are on file at more than 70 public libraries throughout the State. Many reports are free. However, California residents should remember to add the six percent State sales tax when requesting reports for which a charge is made.

77172—950 2-78 OSP 5M

save water

CALIFORNIA DEPARTMENT OF WATER RESOURCES